Section 3.1

## METHOD 2 - DETERMINATION OF STACK GAS VELOCITY AND VOLUMETRIC FLOW RATE

OUTLINE

## SUMMARY

Method 2 outlines a procedure for determining stack gas velocity and volumetric flow rate from stationary sources. A Type S (stauscheibe or reverse) pitot tube or a standard pitot tube meeting the criteria in Section 3.1.1, calibrated according to the procedures outlined in Section 3.1.2, and operated in accordance with Section 3.1.4 is used to measure velocity pressure ($\Delta p$); this pressure measurement, along with gas density, is used to determine the stack gas velocity.

If the minimum criteria of Method 1 are not met or if the measurement site has a swirling or cyclonic gas stream, the procedures outlined in Method 2 for stack gas velocity and volumetric flow rate determination are not applicable. When unacceptable flow conditions exist, alternative procedures such as the use of flow-straightening devices or stack extensions must be employed as necessary to make accurate flow rate determinations. These alternative procedures are subject to approval by the administrator.

The Method Description which follows is based on the Reference Method published August 18, 1977. A complete copy of the Reference Method is contained in Section 3.1.10. Data forms are provided in Section 3.1.12 for the convenience of the Handbook user. Reference 1 was used extensively in preparing the Method Description and the data forms. References 2, 3, 4, and 5 summarize collaborative tests conducted to determine the usefulness and accuracy of this method.

METHOD HIGHLIGHTS

Section 3.1 describes specifications for determination of
stack gas velocity and volumetric flow rate from stationary
sources. The sampling apparatus consists of a pitot tube and
a differential pressure gauge. Stack gas velocity and volumetric
flow rate can be determined in conjunction with other EPA Re-
ference Methods (i.e., Method 5) if the sampling components are
mounted in an interference-free manner.

The results of collaborative tests have shown that the pre-
cision of this test method is adequate for use with other test
methods in determining pollutant emission rates; collaborative
tests also showed that the method is not subject to large biases
from one user to another.[2,5]

The blank data forms at the end of the highlights section
may be removed from the Handbook and used in the pretest, test,
and posttest operations. Each form has a subtitle (e.g.,
Method 2, Figure 2.4) to assist the user in finding a similar
filled-in form in the Method Description (e.g., in Section
3.1.2). On the blank and filled-in forms, the items/parameters
that can cause the most significant errors are indicated with an
asterisk.

1. Procurement of Equipment

Section 3.1.1 (Procurement of Apparatus and Supplies) gives
the specifications, criteria, and design features for equipment
and materials required for performing Method 2 tests. The sam-
pling apparatus can be used in conjunction with sampling equip-
ment required for other methods such as Methods 5 and 8 pre-
sented in this Handbook. This section is designed as a guide in
the procurement and initial check of equipment and supplies. The
activity matrix (Table 1.1) at the end of Section 3.1.1 can be
used as a quick reference; it follows the same order as the
written description in the main text.

2.    Pretest Preparations

Section 3.1.2 (Calibration of Apparatus) provides a step-by-step description of the required calibration procedures. Detailed methods and equipment are described for calibrating pitot tubes in the laboratory and in the field. The calibration section can be removed and compiled, along with calibration sections from all other methods, into a separate quality assurance reference manual for use by calibration personnel. A pretest checklist (Figure 3.1) or similar form should be used to summarize the calibration data.

Section 3.1.3 (Presampling Operations) provides the tester with a guide for supplies and equipment preparation for field tests. The pretest preparation form (Figure 3.2) can be used as an equipment checkout and packing list. The method for packing and the description of packing containers should help to protect the equipment, but are not required.

3.    On-Site Measurements

Section 3.1.4 (On-Site Measurements) contains a step-by-step procedure for performing velocity measurements. Precautions must be taken to ensure that the pitot tube is aligned with the stack gas flow. Also a check for cyclonic flow must be made. The on-site measurement checklist (Figure 4.2) is provided to assist the tester with a quick method of checking requirements.

4.    Posttest Operations

Section 3.1.5 (Postsampling Operations) gives the posttest equipment check procedures. Figure 5.1 or a similar form should be used to summarize the posttest calibration checks, and should be included in the emission test report.

Section 3.1.6 (Calculations) provides the tester with the required equations, nomenclature, and the suggested number of significant digits. It is suggested that a programmed calculator be used if available to reduce the chance of calculation error.

Section 3.1.7 (Maintenance) provides the tester with a guide for a routine maintenance program. This program is not required, but should reduce equipment malfunctions.

5.   Auditing Procedure

Section 3.1.8 (Auditing Procedure) provides a description of necessary activities for conducting performance and system audits.   The performance audits of the data processing and a systems audit of the on-site measurements should provide the independent assessment of the quality of data needed.

Section 3.1.9 (Recommended Standards for Establishing Traceability) recommends the primary standards to which the working standards should be traceable.

6.   References

Sections 3.1.10 and 3.1.11 contain the Reference Method and the suggested references.

PRETEST SAMPLING CHECKS
(Method 2, Figure 3.1)

Date _____ Completed by _____

Pitot Tube

Identification number _____ Date _____

Dimension specifications checked?* _____ yes _____ no

Calibration required? _____ yes _____ no

Date _____ $C_p$ _____

Temperature Sensor

Identification number _____

Calibrated?* _____ yes _____ no

Was a pretest temperature correction used? ____ yes ____ no
  If yes, temperature correction _____ °C (°F)

Barometer

Was the pretest field barometer reading correct?* ___ yes ___ no

Differential Pressure Gauge

Was pretest calibration acceptable?* _____ yes _____ no

*Most significant items/parameters to be checked.

### PRETEST PREPARATIONS
### (Method 2, Figure 3.2)

| Apparatus check | Acceptable | | Quantity required | Ready | | Loaded and packed |
|---|---|---|---|---|---|---|
| | Yes | No | | Yes | No | |
| Pitot Tube<br><br>Type S<br><br>Standard<br><br>Length ____ m(ft)<br><br>Calibrated* _____ | | | | | | |
| Differential<br> Pressure Gauge<br><br>Inclined manom-<br> eter sensitivity<br> _____ cm (in.)<br><br>Other _____ | | | | | | |
| Stack Temperature<br> Sensor<br><br>Type _____<br><br>Calibrated* _____ | | | | | | |
| Orsat Analyzer<br><br>Orsat _____<br><br>Fyrite _____<br><br>Other _____ | | | | | | |

*Most significant items/parameters to be checked.

ON-SITE MEASUREMENTS CHECKLIST
(Method 2, Figure 4.2)

Sampling

Pitot tube, lines, and manometer assembled correctly?* _____

Pitot tube and components mounted in an interference free manner?* _____

Differential pressure gauge has correct sensitivity?* _____

Differential pressure gauge leveled and zeroed?* _____

Pretest leak check? ____ (optional)  Cyclonic flow checked?* ____

Pitot tube parallel to gas flow?* _____

Static pressure measured? _____  Temperature measured? _____

Moisture content determined? _____  Method _____

Orsat samples taken? _____  If no, explain: _____
_____

Posttest leak check performed?* _____ (mandatory)

Data recorded properly? _____

*Most significant items/parameters to be checked.

POSTTEST SAMPLING CHECKS
(Method 2, Figure 5.1)


Pitot Tube

Initial pitot tube coefficient _____
Was pitot tube damaged prior to start of any test runs? _____ yes
_____ no
   If yes, was pitot tube calibrated prior to repair?* __yes ___no
Pitot tube coefficient (damaged) _____ (this value must
 be used for runs started with the damaged pitot tube)


Temperature Sensor

Was a pretest temperature correction used? _____ yes _____ no
   If yes, temperature correction _____ °C (°F) (within 1.5%
   of readings in K (°R) over range)
Average stack temperature of compliance test ($T_s$) _____ K (°R)
Temperature of reference thermometer or solution for recalibra-
   tion* _____ K (°R)
Temperature of stack thermometer for recalibration _____ K (°R)
Difference between reference and stack thermometer temperatures
   ($\Delta T_s$) _____ K (°R)
Do values agree within ±1.5%?* _____ yes _____ no
   If yes, no correction necessary for calculations
   If no, calculations must be done twice, once with recorded,
   values and once with average stack temperature corrected to
   correspond to reference temperature differential ($\Delta T_s$).  Both
   values of final results must then be reported since there is no
   way to determine which is correct

Barometer

Was pretest field barometer reading correct? _____ yes _____ no
Posttest comparison _____ mm (in.) Hg (within ±5.0 mm (0.2 in.)
   Hg of mercury-in-glass barometer)
Was recalibration required? _____ yes _____ no
   If yes, no correction needed when field barometer has the lower
   reading
   If mercury-in-glass reading is lower, subtract the difference
   from the field data readings for the calculations


*Most significant items/parameters to be checked.

1.0  PROCUREMENT OF APPARATUS AND SUPPLIES

Figure 1.1 shows a diagram of the Type S pitot tube-manometer assembly used in this method.  Specifications, criteria and/ or applicable design features are given in this section to aid in the selection of equipment which will produce accurate data. Selection procedures and applicable limits for acceptance checks are also included.  During procurement of equipment and supplies, it is suggested that a procurement log (Figure 1.2) be used to record the descriptive title of equipment; the identification number, if applicable; and the results of the acceptance check. Also, if calibration is required as part of the acceptance check, the data are to be recorded in the calibration log book.  Table 1.1 at the end of this section contains a summary of quality assurance activities for procurement and acceptance of apparatus and supplies.

1.1  Pitot Tube

A Type S pitot tube shown in Figure 1.1 is required.  The pitot tube should be constructed of metal tubing (e.g., 304 or 316 stainless steel) with an external tubing diameter ($D_t$) between 0.48 and 0.95 cm (3/16 and 3/8 in.).  The major criteria in pitot tube construction material are durability and corrosion resistance.  Upon receiving a new pitot tube, inspect it to determine if it was constructed according to the configuration in Figure 1.3.  Repair, replace, or return to the manufacturer any Type S pitot tube which does not meet the face opening specifications outlined in Figure 1.4.  One method of inspecting the construction details is as follows:

1.  Obtain a section of angle aluminum approximately 20 cm (8 in.) long by 1.3 × 2.5 cm (0.5 × 1.0 in.).  Mount a bull's eye level (with ±1° accuracy) to the angle aluminum, as shown in Figure 1.5.

2.  Place the pitot tube in the angle aluminum as shown in Figure 1.5, and level the pitot tube as indicated by the bull's

1.90-2.54 CM
(0.75-1.0 IN.)

7.62 CM
(3 IN.)**

TEMPERATURE SENSOR

FLEXIBLE TUBING
6.25 MM (1/4 IN.)

L*

TYPE S PITOT TUBE

GAS FLOW

LEAK-FREE
CONNECTIONS

MANOMETER

*L = DISTANCE TO FURTHEST SAMPLING
POINT PLUS 30 CM (12 IN.)
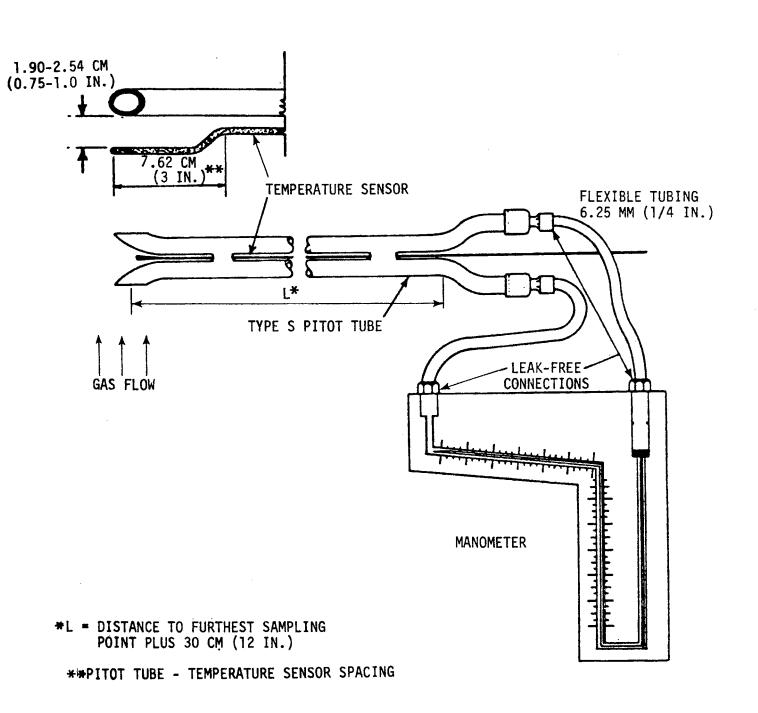
**PITOT TUBE - TEMPERATURE SENSOR SPACING

Figure 1.1   Type S pitot tube-manometer assembly.

| Item description | Quantity | Purchase order number | Vendor | Date Ordered | Date Received | Cost | Disposition | Comments |
|---|---|---|---|---|---|---|---|---|
| Pitot tube | 1 | 76-1208 | Ace Metal | 9-8-79 | 9-24-79 | 8500 | In service | |

Figure 1.2  Example of a procurement log.

A-SIDE PLANE

LONGITUDINAL TUBE AXIS

$D_t$

A

B

$P_A$

$P_B$

NOTE:

$\begin{cases} 1.05 \ D_t < P < 1.50 \ D_t \\ \qquad P_A = P_B \end{cases}$

0.48 CM $\leq D_t \leq$ 0.95 CM
(3/16 IN.) (3/8 IN.)

B-SIDE PLANE

(b)

TRANSVERSE TUBE AXIS

A OR B

(c)

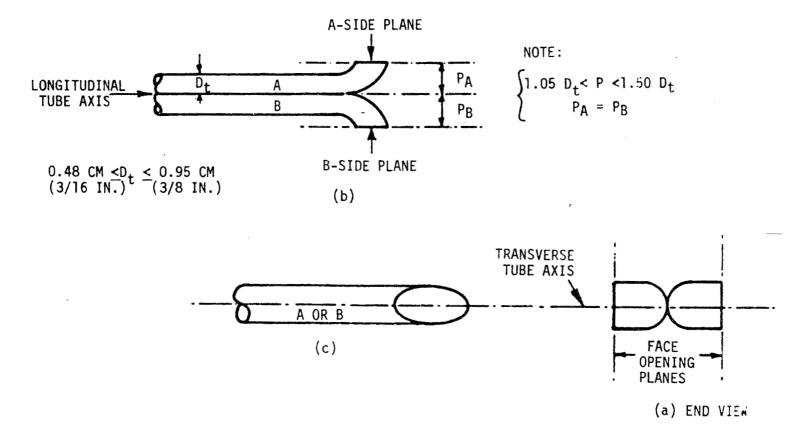FACE OPENING PLANES

(a) END VIEW

Figure 1.3. Properly constructed Type S pitot tube, shown in: (a) end view; face opening planes perpendicular to transverse axis; (b) top view; face opening planes parallel to longitudinal axis; (c) side view; both legs of equal length and centerlines coincident, when viewed from both sides. Baseline coefficient values of 0.84 may be assigned to pitot tubes constructed this way.
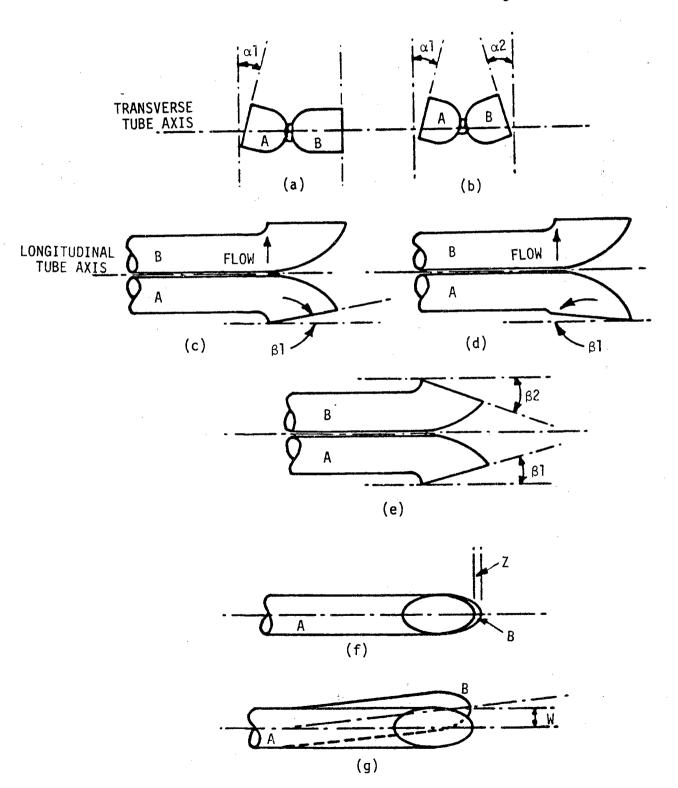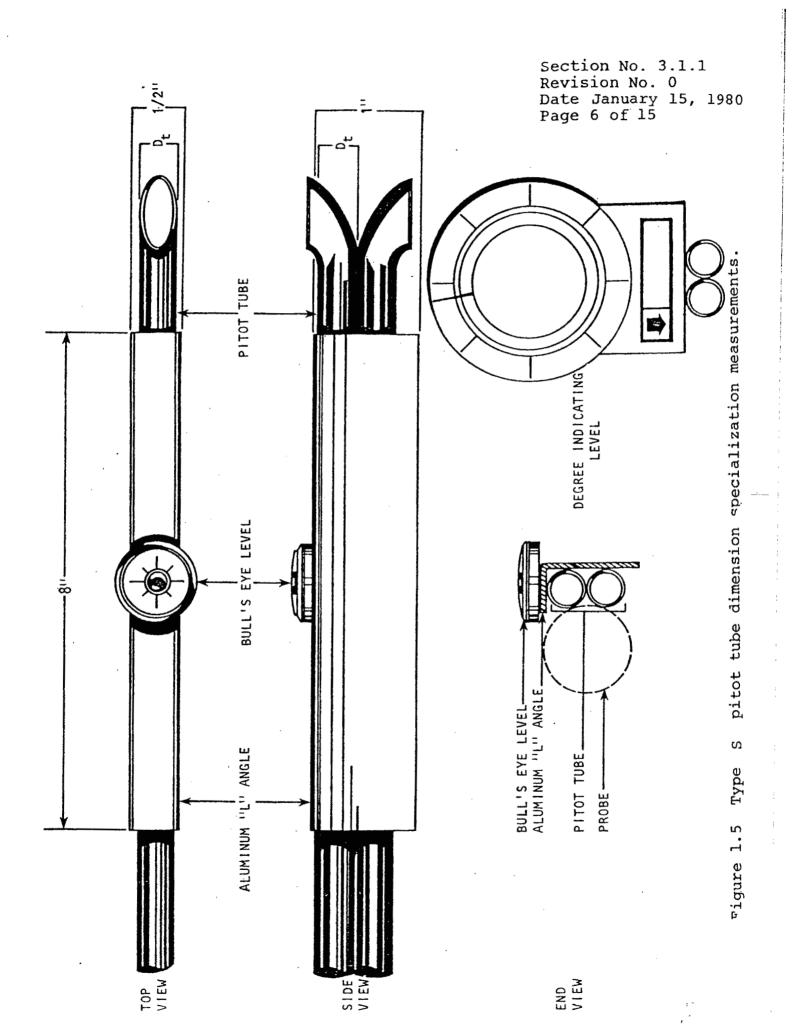
Figure 1.4. Types of face-opening misalignment that can result from field use or improper construction of Type S pitot tubes. These will not affect Cp so long as $\alpha_1$ and $\alpha_2$ <10°, $\beta_2$ <5°, z <0.32 cm (1/8 in.) and w<0.08 cm (1/32 in.).

Figure 1.5  Type S pitot tube dimension specialization measurements.

eye level. A vise may be used to hold the angle aluminum and pitot tube. Note: A permanently mounted pitot tube and probe assembly may require a shorter section of angle aluminum to allow proper mounting on the assembly.

    3. Place a degree indicating level in the various positions, as illustrated in Figure 1.6.

    4. Measure distances $P_a$ and $P_b$.

    5. Measure the external tube diameter ($D_t$) with a micrometer. Record all data on a data form such as Figure 1.7.

    6. Calculate dimensions w and z using the following equations:

$$z = A \sin \gamma \qquad \text{Equation 2-1}$$
$$w = A \sin \theta \qquad \text{Equation 2-2}$$

where,

    z = alignment dimension, cm (in.)
    w = alignment dimension, cm (in.)
    A = distance between tips, ($P_a$ + $P_b$), cm (in.)
    $\gamma$ = angle in degrees
    $\theta$ = angle in degrees.

Note: Pitot tubes with bent or damaged tubing may be difficult to check using this procedure. If the Type S pitot tube meets the face alignment criteria, an identification number should be assigned and permanently marked or engraved on the body of the tube.

    A standard pitot tube (Figure 1.8) may be used instead of a Type S for conducting velocity traverses. Upon receiving a new standard pitot tube, inspect it to determine if it meets the following design criteria:

    1. The tip is of the hemispherical (shown in Figure 1.8), ellipsoidal, or conical design.

    2. There is a minimum of six diameters straight run (based upon $D_1$, the external diameter of the tube) between the tip and static pressure holes.
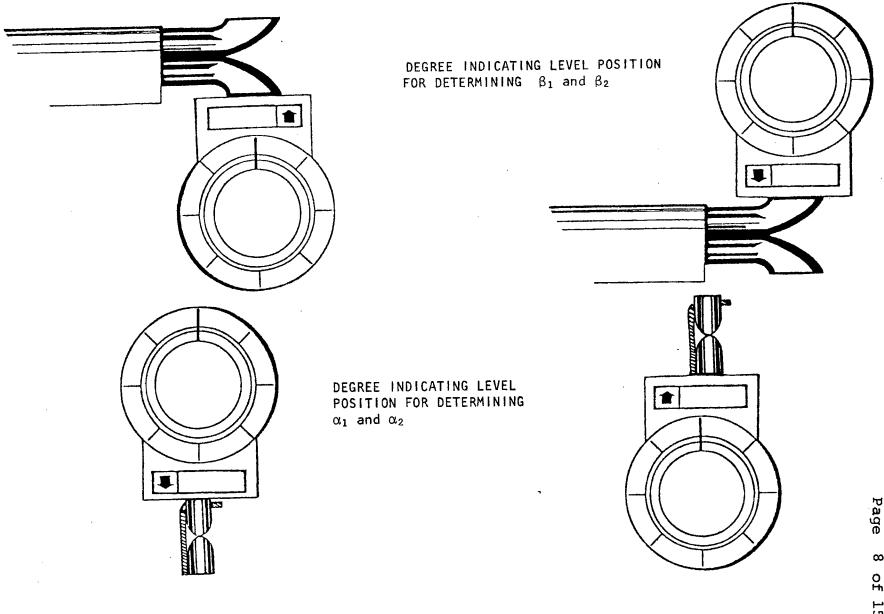
DEGREE INDICATING LEVEL POSITION
FOR DETERMINING $\beta_1$ and $\beta_2$

DEGREE INDICATING LEVEL
POSITION FOR DETERMINING
$\alpha_1$ and $\alpha_2$
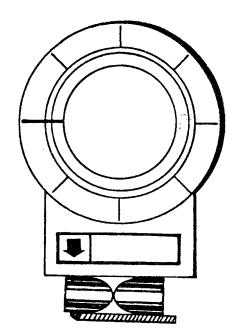
Figure 1.6    Position of dimension measurement.
(continued)
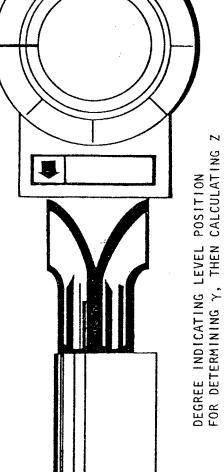
DEGREE INDICATING LEVEL POSITION
FOR DETERMINING γ, THEN CALCULATING Z

DEGREE INDICATING LEVEL
POSITION FOR DETERMINING
Θ, THEN CALCULATING W

Figure 1.6 (continued)

Pitot tube assembly level? _____✓_____ yes _____ no

Pitot tube openings damaged? _____ yes (explain below) __✓__ no

$\alpha_1$ = __2.5__ ° (<10°), $\alpha_2$ = __0.8__ ° (<10°), $\beta_1$ = __0.0__ ° (<5°),

$\beta_2$ = __4.5__ ° (<5°)

$\gamma$ = __3.3__ °, $\theta$ = __1.5__ °, A = _(0.921)_ cm (in.)

z = A sin $\gamma$ = __(0.053)__ cm (in.); <0.32 cm (<1/8 in.),

  w = A sin $\theta$ = __(0.024)__ cm (in.); <0.08 cm (<1/32 in.)

$P_A$ _____(0.461)_____ cm (in.) $P_b$ _____(0.460)_____ cm (in.)

$D_t$ = __(0.289)__ cm (in.)

Comments: _____

_____

_____

Calibration required? _____ yes __✓__ no

Figure 1.7  Type S pitot tube inspection data form.
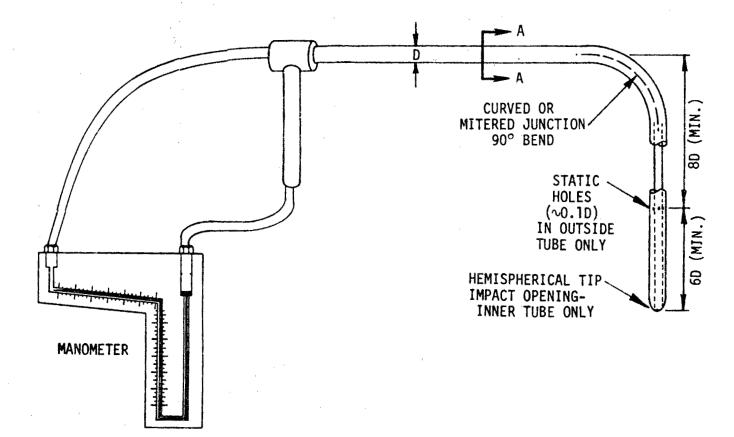
Figure 1.8   Standard pitot tube design specifications.

3.    There is a minimum of eight diameters straight run between the static pressure holes and the centerline of the external tube, following the 90° bend.

4.    The static pressure holes are of equal size (approximately 0.1 D), equally spaced in a piezometer ring configuration.

5.    It has a 90° bend, with curved or mitered junction. Repair, replace or return to the manufacturer any standard pitot tube which does not meet the above criteria.

1.2  Differential Pressure Gauge

A liquid-filled inclined manometer or an equivalent device should be used to measure the velocity head.  Most preassembled sampling trains are equipped with a 10-in. (water column) inclined-vertical manometer that has 0.01-in. divisions on the 0-to-1-in. inclined scale and 0.1-in. divisions on the 1-to-10-in. vertical scale.  This type manometer (or other gauge of equivalent sensitivity) is satisfactory for measurements of $\Delta p$ values as low as 1.3 mm (0.05 in.) $H_2O$.  However, a gauge of greater sensitivity (e.g., with 6.4 mm (0.25 in.) $H_2O$ full scale) is required for stacks with velocity pressures below 1.3 mm (0.05 in.) $H_2O$.

Upon receipt of a new manometer, leak check it using the following procedure:

1.    Level and zero the manometer.

2.    Vent both sides of the manometer to the atmosphere.

3.    Place tygon tubing, or equivalent on the positive leg of the manometer, and blow into the tubing to displace the liquid to at least 30% of scale.

4.    Close off the open end of the tubing, and observe the manometer for 15 s.  If there is no change in the reading, the positive side of the manometer is leak free.

5.    Repeat steps 3 and 4 for the negative side of the manometer, but use suction to produce the manometer reading.

Repair, replace, or return to the manufacturer any manometer which does not pass the leak check.

If differential pressure gauges other than inclined mano-
meters are used (e.g., magnehelic or electronic gauges), cali-
brate the gauges upon receipt using the procedure in Section
3.1.2.

1.3 Temperature Gauge

A thermocouple, liquid-filled bulb thermometer, or other
means capable of measuring temperature to within 1.5% of the
minimum absolute stack temperature is required. Upon receipt,
check the temperature gauge for damage, and then calibrate it
according to the procedure in Section 3.1.2.

1.4 Pressure Probe and Gauge

Leak-free tubing and a mercury-or water-filled U-tube manom-
eter capable of measuring stack pressure to within 2.5 mm (0.1
in.) Hg is required. The static tap of a standard type pitot
tube or one leg of a Type S pitot tube with the face openings
positioned parallel to the gas flow may also be used as the
pressure probe. The differential pressure gauge used for veloc-
ity measurements can be used to measure static pressure.

Upon receipt of a U-tube manometer, leak check according to
the procedure in Subsection 1.1.2.

1.5 Barometer

A mercury, aneroid, or other barometer capable of measuring
atmospheric pressure to within 2.5 mm (0.1 in.) Hg is required.
Upon receipt of a new barometer, check it against a mercury-in-
glass barometer or the equivalent. If the barometer cannot be
adjusted to agree within 2.5 mm (0.1 in.) Hg of the reference
barometric pressure, it should be returned to the manufacturer.

1.6 Gas Analyzer

To analyze gas composition for determining dry molecular
weight of the gases from combustion or other unknown streams, use
Method 3. For processes emitting essentially air, use a dry
molecular weight of 29.0. Use Method 4 or Method 5 for moisture
content determinations.

## 1.7  Calibration Pitot Tube

Standard type, to calibrate the Type S pitot tube.  The standard type pitot tube should have a known coefficient obtained from the National Bureau of Standards (NBS), Route 70 S, Quince Orchard Road, Gaithersburg, Maryland, or the standard pitot tube must be calibrated against another standard pitot tube with an NBS-traceable coefficient.  Alternatively, a standard pitot tube designed according to the criteria given in Subsection 1.1.1 and illustrated in Figure 1.8 may be used.  Be sure to inspect the standard type pitot tube for any damage upon receipt.

## 1.8  Differential Pressure Gauge

An inclined manometer or equivalent is used for Type S pitot tube calibration.  This should be an easily readable, sensitive gauge for laboratory use.  If the single-velocity calibration technique is used (Section 3.1.2), the calibration differential pressure gauge should be readable to the nearest 0.13 mm (0.005 in.) $H_2O$.  For multivelocity calibrations, the gauge shall be readable to the nearest 0.13 mm (0.005 in.) $H_2O$ for $\Delta p$ values between 1.3 and 25 mm (0.05 and 1.0 in.) $H_2O$, and to the nearest 1.3 mm (0.05 in.) $H_2O$ for $\Delta p$ values above 25 mm (1.0 in.) $H_2O$.  A special, more sensitive gauge will be required to read $\Delta p$ values below 1.3 mm (0.05 in.) $H_2O$.  Visually check and leak check the calibration differential pressure gauge upon receipt.

Table 1.1  ACTIVITY MATRIX FOR PROCUREMENT OF APPARATUS

| Apparatus | Acceptance limits | Frequency and method of measurement | Action if requirements are not met |
|---|---|---|---|
| All apparatus | No visible damage | Visual check when purchased | Return to supplier immediately |
| Pitot tube (Type S or equivalent) | See Figs 1.3 and 1.4 for acceptance limits | Measure dimensions and alignment; identify upon receipt | Do not use if alignment is not within limits; repair or replace |
| Differential pressure gauge | No leaks | When purchased, visually inspect and leak check | Adjust or return to supplier |
| Temperature gauge | Capable of measuring temperature within 1.5% of minimum absolute stack temperature | Calibrate according to Section 3.1.2 | Return to supplier or repair |
| Pressure probe and gauge | Capable of measuring stack pressure within 2.5 mm Hg (0.1 in.) Hg; no leaks | Visual inspection and leak check | Adjust to correct for error, or return to supplier |
| Calibration pitot tube | Meet design specifications with known coefficient from NBS, or see Sec 1.1 | Visual check | Return to supplier |
| Calibration differential pressure gauge | No leaks; single point-capable of measuring $\Delta p$ to within 0.13 mm (0.005 in.) $H_2O$; multipoint readable within 0.13 mm (0.005 in.) $H_2O$ for $\Delta p$ values between 1.3 and 25 mm (0.05 and 1.0 in.) and to nearest 1.3 mm (0.05 in.) $H_2O$ for $\Delta p$ values >25 mm (110 in.); special sensitivity for values <1.3 mm (0.05 in.) $H_2O$ | Visual check and leak check | Repair or replace |

## 2.0 CALIBRATION OF APPARATUS

Calibration of apparatus is one of the most important functions in maintaining data quality. The detailed calibration procedures in this section are designed for the equipment specified by Method 2 and described in the previous section. A laboratory log book of all calibrations must be maintained. Table 2.1 at the end of this section summarizes the quality assurance activities for calibration.
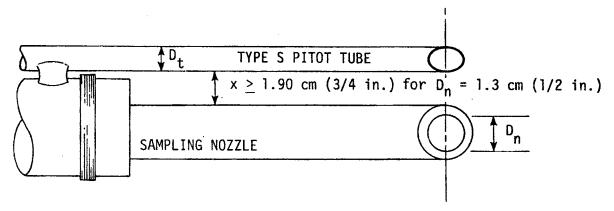
### 2.1 Type S Pitot Tube

A pitot tube that meets the face opening specifications in Section 3.1.1 (Figures 1.3 and 1.4) and that has the following dimensions--external tubing diameter ($D_t$) between 0.48 and 0.95 cm (3/16 and 3/8 in.) and $P_A$ and $P_B$ equal and between 1.05 and 1.50 $D_t$--either may be assigned a baseline (isolated tube) coefficient value of 0.84 or may be calibrated. Note, however, that if the pitot tube is mounted on a probe thermocouple assembly and if the components of the assembly do not meet the interference free criteria in (Subsection 2.1.1), calibration will be required despite knowledge of the baseline coefficient value.

If $D_t$, $P_A$, and $P_B$ are outside the specified limits, the pitot tube must be calibrated as outlined in Subsection 2.1.2.

### 2.1.1 Pitot Tube Assemblies - Interference-free assemblies--that is, pitot tubes mounted with a temperature sensor, probe, and nozzle--are shown in Figures 2.1 and 2.2. When the pitot tube meets the previously described dimensions and specifications and is mounted according to the specifications in Figures 2.1 and 2.2, no calibration is required and the baseline (isolated tube) coefficient of 0.84 may be used. Dimensions of the pitot tube - probe sampling assembly must be carefully measured with an internal caliper or a steel machinist's rule.
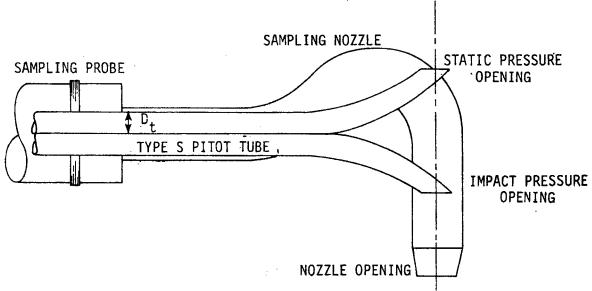
Note: Only pitot tubes constructed of 0.48 to 0.95 cm (3/16 to 3/8 in.) tubing can be used in interference-free assemblies. All other assemblies must be calibrated.

TYPE S PITOT TUBE

$D_t$

$x \geq 1.90$ cm (3/4 in.) for $D_n$ = 1.3 cm (1/2 in.)

SAMPLING NOZZLE

$D_n$

(a)  BOTTOM VIEW: SHOWING MINIMUM PITOT-NOZZLE SEPARATION.

SAMPLING NOZZLE

SAMPLING PROBE

STATIC PRESSURE
OPENING

$D_t$

TYPE S PITOT TUBE

IMPACT PRESSURE
OPENING

NOZZLE OPENING

(b)  SIDE VIEW:  TO PREVENT PITOT TUBE FROM INTERFERING WITH
GAS FLOW STREAMLINES APPROACHING THE NOZZLE, THE IMPACT
PRESSURE OPENING PLANE OF THE PITOT TUBE SHALL BE EVEN
WITH OR DOWNSTREAM FROM THE NOZZLE ENTRY PLANE

Figure 2.1  Required pitot tube-sampling nozzle configuration
to prevent aerodynamic interference; buttonhook-type nozzle;
centers of nozzle and pitot opening aligned; in respect to flow
direction, $D_t$ between 0.48 and 0.95 cm (3/16 and 3/8 in.).

Figure 2.2   Required thermocouple and probe placement to prevent interference: $D_t$ between 0.48 and 0.95 cm (3/16 and 3/8 in.).

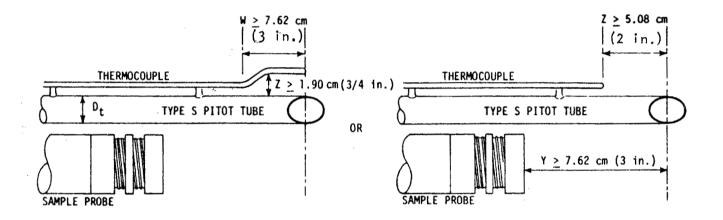2.1.2  Calibration Setup - A test setup for calibrating the pitot tube can be constructed in the laboratory from a straight section of duct that is 10 to 12 duct diameters long, as shown in Figure 2.3.  The diameter of a circular duct must be at least 30.5 cm (12 in.), and the width (shorter side) of a rectangular duct of the same area must be at least 25.4 cm (10 in.).  For a rectangular cross section, an equivalent circular diameter calculated from the following equation should be used to determine the required minimum length.

$$D_e = \frac{2\ L\ W}{(L + W)}$$  Equation 2-1

where

$D_e$ = equivalent diameter,
L  = length of one side of duct, and
W  = width of other side of duct

To ensure stable, fully developed flow patterns at the calibration site or at the "test section," this site must be located at least eight diameters downstream and two diameters upstream from any flow disturbance such as a bend, change in cross section, fan, or opening.

The eight- and two-diameter criteria are not absolute, and other test section locations may be used (subject to approval of the administrator), provided that the flow at the test site is stable and parallel to the duct axis.  This may be achieved by using flow straighteners.

The flow system should generate a test section velocity of about  915 m/min (3000 ft/min);  this velocity must be constant with time to guarantee steady flow during calibration.  Type S pitot tube coefficients obtained by single-velocity calibration at 915 m/min (3000 ft/min) will generally be valid to within ±3% for the measurement of velocities above 305 m/min (1000 ft/min) and to within ±6% for those between 180 and 305 m/min (600 and
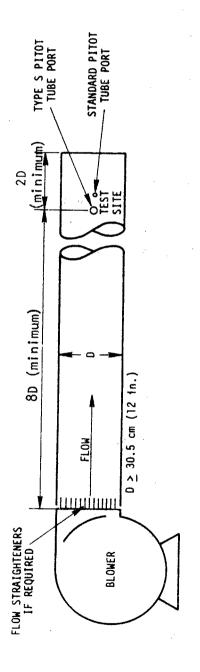
Figure 2.3  Pitot tube calibration system.

1000 ft/min). A more precise correlation between $C_p$ and velocity can be obtained if at least four distinct velocities ranging from 180 to 1525 m/min (600 to 5000 ft/min) are used.[7,8]

Two entry ports--one each for the standard and for the Type S pitot tubes--should be cut in the test section, as shown in Figure 2.4. The standard pitot entry port should be slightly downstream of the Type S port, so that the standard and Type S impact openings will lie in the same cross-sectional plane during calibration. The exact distance between openings depends on the standard pitot tube diameter. To facilitate alignment of the pitot tubes during calibration, the test section should be constructed of plastic or some transparent material.

A permanently mounted manometer should be provided near the calibration site. Plastic tubing and two-way valves will facilitate connecting the manometer to the pitot tubes and in switching from one pitot tube to another. Pitot tube holders should be used to maintain the alignment and location of each pitot tube during calibration.

2.1.3 <u>Calibration Procedure</u> - One leg of the Type S pitot tube should be marked with an "A" and the other with a "B." To obtain calibration data for both the A and B sides, proceed as follows:

1. Clean and fill the manometer with clean fluid of the proper density. Inspect and leak check all pitot lines and fittings; repair or replace if necessary.

2. Assemble the apparatus, as shown in Figure 2.4.

3. Level and zero the inclined manometer. Turn on the fan, and allow the flow to stabilize. Seal the Type S entry port with duct tape.

4. Position the standard type pitot tube near the center of the duct, and seal the entry port with duct tape or other means. Check to be sure that the pitot tube is properly aligned and perpendicular to the duct.
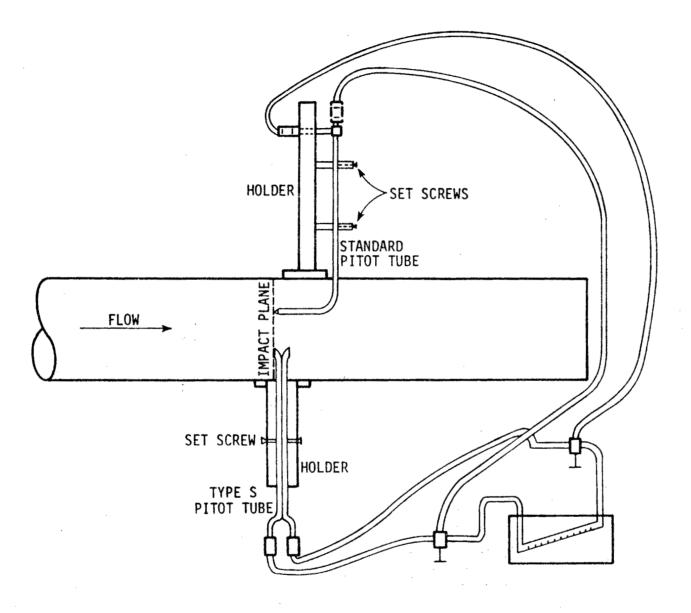
Figure 2.4   Pitot tube calibration set-up.

5. Adjust the fan speed or intake area to give a desired velocity head, as measured by the standard pitot tube, and record $\Delta p_{std}$ on a form such as Figure 2.5. Check the reading again; withdraw this pitot tube; and seal the opening.

6. Connect the Type S pitot tube to the manometer. Insert the Type S tube, and locate the tip at the same point in the duct as that measured by the standard tube.

7. Align the Type S tube with leg A facing directly up-stream. Alignment of the pitot tube along the roll and pitch axes is best accomplished by visually aligning it against the duct. Seal the entry port with a rag or duct tape. Figures 2.6 and 2.7 illustrate the magnitude and characteristics of measurement errors in $C_p$ associated with varying degrees of nonalignment on the roll (yaw) and pitch axes, respectively.

8. Read and record the velocity head, $\Delta p_s$ in Figure 2.5. Remove the Type S tube from the duct, and disconnect the manometer.

9. Repeat steps 4 through 8 above until three sets of velocity head measurements are obtained.

10. Repeat the complete procedure with leg B of the Type S pitot tube facing upstream.

11. Calculate the Type S pitot tube coefficient, $C_{p(S)}$, for each set of measurements, using Equation 2-2.

$$C_{p(S)} = C_{p(std)}\sqrt{\frac{\Delta p_{std}}{\Delta p_s}} \qquad \text{Equation 2-2}$$

where

$C_{p(S)}$ = Type S pitot tube coefficient,

$C_{p(std)}$ = standard pitot tube coefficient (use 0.99 if coefficient is unknown and tube is designed according to guidelines in Section 3.1.1),

$\Delta p_{std}$ = velocity head measured by the standard pitot tube, cm (in.) $H_2O$, and

$\Delta p_s$ = velocity head measured by the Type S pitot tube, cm (in.) $H_2O$.

Calibration pitot tube: type __S__ size (OD) $\frac{3}{8}''$ ID number _FL-1_

Type S pitot tube ID number ___34___ $c_{p(std)}$ = __0.99__

Calibration: date _Sept 1, 1979_ performed by _H. Brown_

### A-Side Calibration

| $\Delta p_{std'}$ cm (in.) $H_2O$ | $\Delta p_{S'}$ cm (in.) $H_2O$ | $c_{p(S)}$ [a] | DEV. [b] |
|---|---|---|---|
| 0.060 | 0.085 | 0.833 | 0.008 |
| 0.075 | 0.105 | 0.837 | 0.003 |
| 0.090 | 0.125 | 0.840 | 0.0 |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| Average | | 0.84 | 0.0037 |

### B-Side Calibration

| $\Delta p_{std'}$ cm (in.) $H_2O$ | $\Delta p_{S'}$ cm (in.) $H_2O$ | $c_{p(S)}$ [a] | DEV. [b] |
|---|---|---|---|
| 0.065 | 0.09 | 0.841 | 0.001 |
| 0.080 | 0.11 | 0.844 | 0.004 |
| 0.095 | 0.13 | 0.846 | 0.006 |
| | | | |
| | | | |
| Average | | 0.84 | 0.0037 |

$$^a c_{p(S)} = c_{p(std)} \sqrt{\frac{\Delta p_{std}}{\Delta p_S}} = \underline{0.84}.$$

$^b DEV = c_{p(S)} - \bar{c}_{p'}$ (must be $\leq 0.01$)

$\bar{\bar{c}}_p(A) - \bar{\bar{c}}_p(B) = \underline{\quad O \quad}$ (must be $\leq 0.01$)

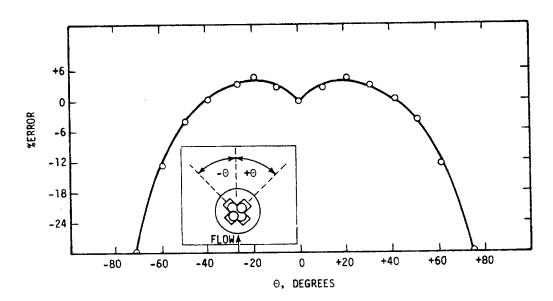Figure 2.5 Pitot tube calibration data.

Figure 2.6   Example of error in measured stack gas velocity as a
function of tube misalignment along its roll axis (yaw).



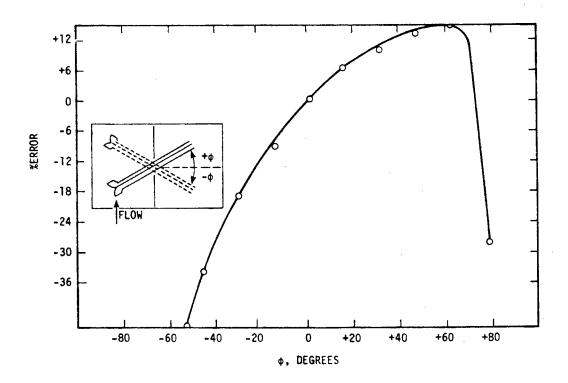Figure 2.7   Example of error in measured stack gas velocity as a
function of tube misalignment along its pitch axis.

12.    Calculate $\bar{C}_p(A)$ and $\bar{C}_p(B)$, the average A-side and B-side coefficients, and the difference between these two averages.

13.    Calculate the deviation of each of the three A-side values of $C_{p(S)}$ from $\bar{C}_p(A)$, and the deviation of each B-side value of $C_{p(S)}$ from $\bar{C}_p(B)$, using Equation 2-3.

$$\text{Deviation} = C_{p(S)} - \bar{C}_p \ (A \text{ or } B). \qquad \text{Equation 2-3}$$

14.    Calculate s, the estimated standard deviation of the deviations from the mean for both the A and B sides of the pitot tube using Equation 2-4.

$$s \ (A \text{ or } B) = \left( \frac{\sum\limits_{1}^{3} [C_{p(S)} - \bar{C}_p \ (A \text{ or } B)]^2}{2} \right)^{1/2}. \qquad \text{Equation 2-4}$$

Use the Type S pitot tube assembly only if the values of s for both A and B are ≤0.02 and if the absolute value of the difference between $\bar{C}_p(A)$ and $\bar{C}_p(B)$ is ≤0.01.

2.1.4  Special Calibration Considerations - The pitot tube-probe assembly may block a significant part of the flow in ducts <91 cm (36 in.) in diameter.  This blockage, in turn, affects the pitot tube calibration factor.  To check for any blockage effects, use the following procedure:

1.    Make a projected-area model of the pitot tube assembly with the Type S pitot tube impact opening positioned at the center of the duct (Figure 2.8).  This model represents the approximate "average blockage" of the duct cross section during calibration or during a sample traverse.  Although the actual blockage will be less than this for sample points close to the near stack wall and more than this for points close to the far wall, the model approximates the average condition.

2.    Calculate the theoretical average blockage by taking the ratio of the projected area of the probe sheath to the cross

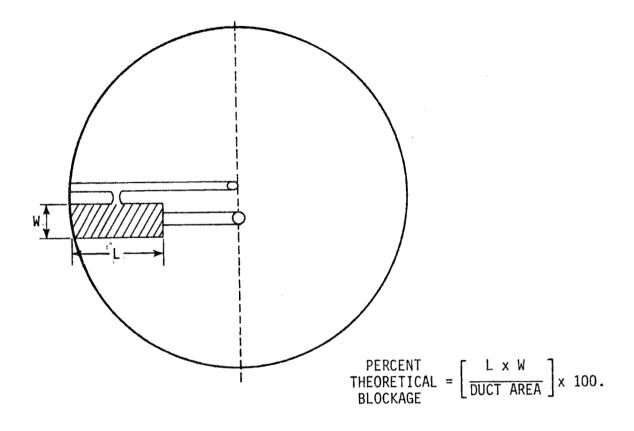NOTE: A PITOT TUBE ASSEMBLY WITH
NO EXTERNAL SHEATH IS SHOWN.



$$\text{PERCENT THEORETICAL BLOCKAGE} = \left[ \frac{L \times W}{\text{DUCT AREA}} \right] \times 100.$$

Figure 2.8.   Projected-area model for sampling of small
ducts with pitot tube assemblies.

sectional area of the duct (use consistent units of measure), and multiply by 100. If the theoretical blockage is either $\leq$2% for an assembly with an external sheath or $\leq$3% for an assembly without an external sheath, the decrease in $C_p$ will be <1% and no adjustment in the pitot tube coefficients will be necessary. If the theoretical blockage exceeds these values, apply a correction factor, as shown in Figure 2.9. During calibration, the blockage effect can be minimized by keeping the pitot tube approximately halfway between the near side wall and the center.

2.1.5 Recalibration - After each field use, the isolated pitot tubes must be carefully examined and their dimensions checked, as specified in Section 3.1.1. If damaged, a tube must either be repaired to conform with the acceptable dimensions or be discarded. Pitot tube assembly dimensions must also be carefully checked. If the component spacings have not changed and if alignment is intact, the assembly may be reused with the same correction factor. If the spacings have changed, either restore the original spacing or recalibrate. No correction to the field data is required for runs that were started with acceptable pitot tubes. If the pitot tube is damaged, it may be replaced using an interference-free spacing, as shown in Section 2.1; otherwise, the assembly should be recalibrated.

Standard pitot tubes need not be recalibrated. If they are damaged, they should be replaced.

2.2 Stack Temperature Sensor

The stack temperature sensor should be calibrated upon receipt or checked before field use. Each sensor should be uniquely marked for identification. The calibration should be performed at three points and then extrapolated over the range of temperatures anticipated during actual sampling. For the three point calibration, a reference mercury-in-glass thermometer should be used.

The following procedure is recommended for calibrating stack temperature sensors (thermocouples and thermometers) for field use.[11]
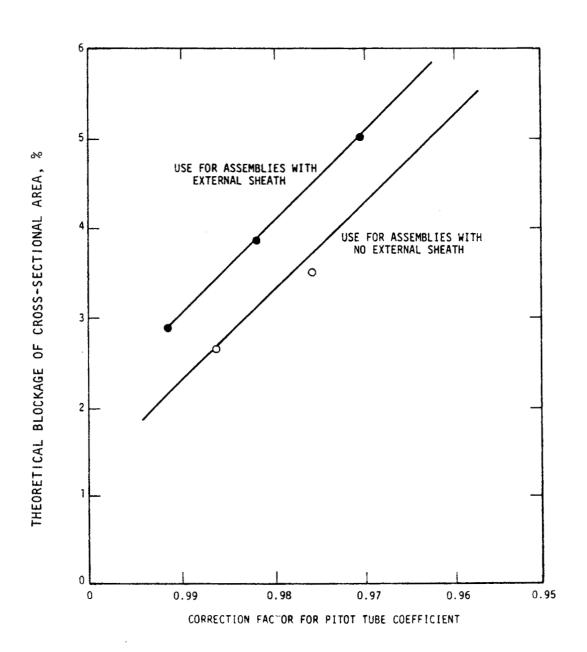
Figure 2.9   Adjustment of Type S pitot tube coefficients to account for blockage effects in duct <91 cm in diameter.

1.   For the ice point calibration, form a slush from crushed ice and liquid water (preferably deionized, distilled) in an insulated vessel such as a Dewar flask.

Taking care that they do not touch the sides of the flask, insert the stack temperature sensor into the slush to a depth of at least 2 in.  Wait 1 min to achieve thermal equilibrium, and record the readout on the potentiometer.  Obtain three readings taken in 1-min intervals.  <u>Note</u>:  Longer times may be required to attain thermal equilibrium with thick-sheathed thermocouples.

2.   Fill a large Pyrex beaker with water to a depth $\geq 4$ in. Place several boiling chips in the water, and bring the water to a full boil using a hot plate as the heat source.  Insert the stack temperature sensor(s) in the boiling water to a depth of at least 2 in., taking care not to touch the sides or bottom of the beaker.

Alongside the sensor(s), an ASTM reference thermometer should be placed.  If the entire length of the mercury shaft in the thermometer cannot be immersed, a temperature correction will be required to give the correct reference temperature.

After 3 min, both instruments will attain thermal equilibrium.  Simultaneously record temperatures from the ASTM reference thermometer and the stack temperature sensor three times at 1-min intervals.

3.   For thermocouple, repeat Step 2 with a liquid that has a boiling point (such as cooking oil) in the 150° - 250°C (300° - 500°F) range.  Record all data on Figure 2.10.  For thermometers, other than thermocouples, repeat Step 2 with a liquid that boils at the maximum temperature that the thermometer is to be used, or place the stack thermometer and reference thermometer in a furnace or other device to reach the required temperature. <u>Note</u>:  If the thermometer is to be used at temperatures higher than the reference thermometers will record, the stack thermometer may be calibrated with a thermocouple previously calibrated with the above procedure.

Date ___*August 2, 1979*___ Thermocouple number ___*16*___

Ambient temperature ___*21.1*___ °C  Barometric pressure ___*29.43*___ in. Hg

Calibrator ___*T. Watkins*___ Reference:  mercury-in-glass ___*ASTM 3C*___

other _____

| Reference point number[a] | Source[b] (specify) | Reference thermometer temperature, °C | Thermocouple potentiometer temperature, °C | Temperature difference,[c] % |
|---|---|---|---|---|
| 0° | ice water | 1°C | 1°C | — |
| 100° | boiling water | 101.5°C | 101.0°C | 0.1% |
| — | boiling cooking oil | 205.5°C | 205°C | 0.5% |

[a]Every 30°C (50°F) for each reference point.

[b]Type of calibration system used.

[c]$\left[ \dfrac{(\text{ref temp, °C} + 273) - (\text{test thermom temp, °C} + 273)}{\text{ref temp, °C} + 273} \right] 100 \leq 1.5\%.$

Figure 2.10  Stack temperature sensor calibration data form.

4.   If the absolute temperature values of the reference thermometer and thermocouple(s) agree within ±1.5% at each of the three calibration points, plot the data on linear graph paper and draw the best-fit line between the points or calculate the linear equation using the least-squares method.  The data may be extrapolated above and below the calibration points and cover the entire manufacturer's suggested range for the thermocouple.  For the portion of the plot or equation that agrees within 1.5% of the absolute reference temperature, no correction need be made.  For all other portions that do not agree within ±1.5% use the plot or equation to correct the data.

If the absolute temperature values of the reference thermometer and stack temperature sensor (other than the thermocouple) agree within ±1.5% at each of the three points, the thermometer may be used over the range of calibration points for testing without applying any correction factor.  The data cannot be extrapolated outside the calibration points.

2.3  Barometer

The field barometer should be adjusted initially and before each test series to agree within 2.5 mm (0.1 in.) Hg of the mercury-in-glass barometer or the station pressure value reported by a nearby National Weather Service station corrected for elevation.  The correction for elevation difference between the weather station and sampling point should be applied at a rate of -2.5 mm (0.1 in.) Hg/30 m (100 ft).  Record the results on the pretest sampling check form or on a similar form, as shown in Section 3.1.3.

2.4  Differential Pressure Gauge

Differential pressure gauges other than inclined manometers must be calibrated initially, and their calibration must be checked after each test series.  Calibrate and check the differential pressure gauge using the following procedure:

1.   Connect the differential pressure gauge to a gauge-oil manometer, as illustrated in Figure 2.11.

TO PRESSURE SOURCE OR
VENTED TO ATMOSPHERE

DIFFERENTIAL PRESSURE
GAUGE

VALVE

VALVE

TO VACUUM SYSTEM OR
VENTED TO ATMOSPHERE

MANOMETER
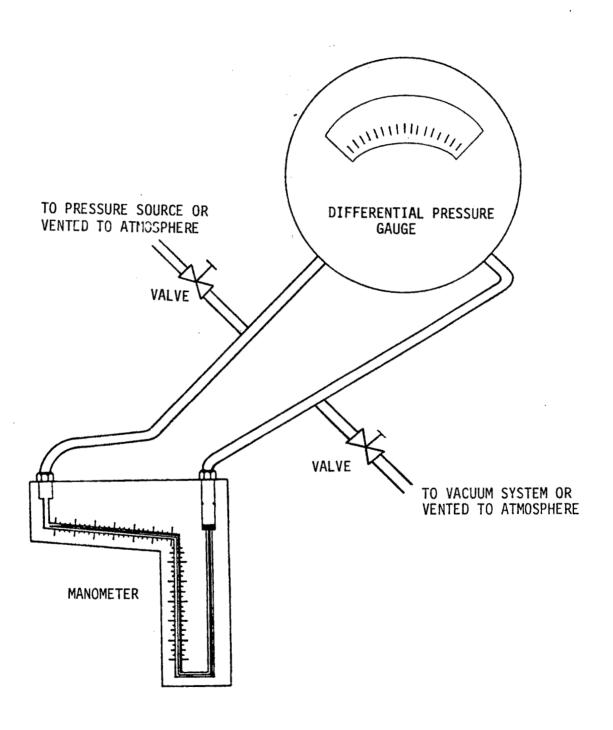
Figure 2.11 Differential pressure gauge check.

2.    Vent the vacuum side to the atmosphere, and place a pressure on each system.

3.    Compare $\Delta p$ readings of the differential pressure gauge with those of the gauge-oil manometer at a minimum of three points representing approximately the range of $\Delta p$ values to be encountered.  Follow the same procedures on the vacuum side by venting the pressure side to the atmosphere and by putting a vacuum on the system.

4.    The posttest calibration should be performed at the average $\Delta p$.  If the agreement is within ±5% the calibration is acceptable; if not, void the data or consult the administrator to determine acceptability.

5.    Record the data on a form such as Figure 2.12.  If, at each point, the value of $\Delta p$ as read by the differential pressure gauge and the gauge-oil manometer agree within 5%, the differential pressure gauge should be considered properly calibrated.

Gauge type _Magnehelic_   Serial or ID number _0074_

Scale _____ _0-1"_ _____

| Gauge-oil manometer Δp | | Differential pressure gauge Δp | Pressure difference % |
|---|---|---|---|
| | 0.1 | 0.1 | 0 |
| Side A | 0.15 | 0.15 | 0 |
| | 0.20 | 0.20 | 0 |
| | | | 0 |
| | 0.1 | 0.1 | 0 |
| Side B | 0.15 | 0.15 | 0 |
| | 0.20 | 0.20 | 0 |

Calibration:  initial _____   posttest ___✓___

Date calibrated _August 4, 1979_   by ___T. Watkins___

Figure 2.12  Differential pressure gauge calibration data form.

Table 2.1  ACTIVITY MATRIX FOR CALIBRATION OF APPARATUS

| Apparatus | Acceptance limits | Frequency and method of measurement | Action if requirements are not met |
|---|---|---|---|
| Type S pitot tube and/or probe assembly | All dimension specifications met, or calibrate according to Sec 3.1.2, and mount in an interference free manner | When purchased, use method in Secs 3.1.1 and 3.1.2; visually inspect after each field test | Do not use pitot tubes that do not meet face opening specifications; repair or replace as required |
| Stack gas temperature measurement system | Capable of measuring within 1.5% of minimum stack temperature (absolute) | When purchased and after each field test, calibrate against ASTM 3C or 3F thermometer | Adjust to agree with Hg bulb thermometer, or construct a calibration curve to correct the readings |
| Barometer | Agrees within 2.5 mm (0.1 in.) Hg of mercury-in-glass barometer | Initially and after every field use, compare to a liquid-in-glass barometer | Adjust, repair, or discard |
| Differential pressure gauge (does not include inclined manometers) | Agree within ±5% of inclined manometers | Initially and after each field use | Reject test results, or consult administrator if post-test calibration is out of specification |

3.0  PRESAMPLING OPERATIONS

The quality assurance activities for presampling prepara-
tions are summarized in Table 3.1 at the end of this section.
See Section 3.0 of this Handbook for details on preliminary site
visits.

3.1  Apparatus Check and Calibration

Figures 3.1 and 3.2 or similar forms are recommended to aid
the tester in recording calibration data and in preparing an
equipment checklist, status form, and packing list.

3.1.1  Type S Pitot Tube and Differential Pressure Gauge  -  For
the Type S pitot tube and inclined manometer assembly illustrated
in Figure 1.2, the following checks should be made before each
field test.

1.  Visually inspect the pitot tube openings for damage
such as a scratch, nick, or dent that would tend to disrupt the
air flow pattern.  Check for proper alignment; that is, the cen-
ters of the two openings should be in a straight line such that
when one opening is directed upstream, the other will be exactly
180° opposite, pointing downstream.  If the damage or misalign-
ment is obvious when visually inspected, the pitot tube should be
replaced or repaired.  Check the weld spots holding the two legs
together; if broken, repair.  Calibration must be checked after
repair if the pitot tube does not conform to specifications.

2.  Check the quick disconnects on the pitot tube and check
the connecting lines for proper operation.  Clean the small metal
parts of the disconnect.  Lubricate sparingly to help to keep
them free.

3.  Blow out the pitot tube legs from the line ends with
compressed air, rinse with distilled water then with acetone, and
dry with compressed air.

4.  Visually inspect the differential pressure gauge for
damage.  Repair or replace as necessary.  Level the inclined

Date _August 1, 1979_  Completed by _T. Watkins_

Pitot Tube

Identification number _34_  Date _August 1, 1979_

Dimension specifications checked?* _✓_ yes _____ no

Calibration required? _____ yes _✓_ no

Date _____ $C_p$ _0.84_

Temperature Sensor

Identification number _16_

Calibrated?* _✓_ yes _____ no

Was a pretest temperature correction used? _____ yes _✓_ no
   If yes, temperature correction _____ °C (°F)

Barometer

Was the pretest field barometer reading correct?* _✓_ yes _____ no

Differential Pressure Gauge

Was pretest calibration acceptable?* _✓_ yes _____ no

*Most significant items/parameters to be checked.

Figure 3.1  Pretest sampling checks.

| Apparatus check | Acceptable | | Quantity required | Ready | | Loaded and packed |
|---|---|---|---|---|---|---|
| | Yes | No | | Yes | No | |
| **Pitot Tube** <br> Type S <br> Standard <br> Length _5_ m̶(ft) <br> Calibrated* ✓ | ✓ | | 3 | ✓ | | yes |
| **Differential Pressure Gauge** <br> Inclined manometer sensitivity _0-.25_ c̶m̶ (in.) <br> Other _____ | ✓ | | 3 | ✓ | | yes |
| **Stack Temperature Sensor** <br> Type Thermocouple <br> Calibrated* yes | ✓ | | 3 | ✓ | | yes |
| **Orsat Analyzer** <br> Orsat ____ ✓ <br> Fyrite ____ ✓ <br> Other _____ | ✓ <br> ✓ | | 2 <br> 2 | ✓ <br> ✓ | | yes <br> yes |

*Most significant items/parameters to be checked.

Figure 3.2  Pretest preparation check.

manometer (if used as the differential pressure gauge), and fill with the proper specific gravity fluid; this recommended fluid is usually inscribed on the manometer. Check for leaks, especially around the fluid level plunger and drain screws. Replace the fluid level plunger or O-rings if leaks are detected. Clean the manometer when it is dirty and change the fluid at any sign of fading. If other differential pressure gauges are used, follow the manufacturer's check-out instructions.

5. Connect the pitot tube and differential pressure gauge with the pitot tube lines. Check for obstructions by blowing lightly on one pitot tube leg and then the other; watch the responses of the gauge. Also check for leaks by blowing into the downstream leg, sealing the opening, and noting any drop in the pressure gauge reading. Check the upstream leg by drawing a slight vacuum, sealing, and noting the gauge. If there are no leaks, the gauge readings will remain constant. No change in the differential pressure gauge reading should occur.

6. Check the manometer fluid reservoir for proper adjustment. A standard 0-254 mm (0-10 in.) $H_2O$ manometer should be able to adjust ±1.3 mm (0.05 in.) $H_2O$.

3.1.2 <u>Temperature Measurement System</u> - The following temperature gauge checks should be made before each field test:

1. Visually check the readout device, sensor, and interconnecting lines or wires as applicable for general appearance. If damage is detected, repair or replace as necessary.

2. Compare the ambient temperature readings made with the temperature measuring system to those made with a mercury-in-glass thermometer. If the system does not agree within ±4°C (this is less than ±1.5% at about 293K, which is near room temperature) of the thermometer, the temperature measuring system should be calibrated as directed in Section 3.1.2. Otherwise, record the two readings in the calibration log book and date and initial the entries.

3.1.3 <u>Barometer</u> - Check the field barometer reading against that of a mercury barometer. If they disagree more than ±2.3 mm

(0.1 in.) of mercury, adjust the field barometer until it agrees with the mercury barometer. Record the two readings in the calibration log book; date and initial the entries.

## 3.2 Packing Equipment for Shipment

The logistics, time of sampling, and quality of data of any source testing method are dependent upon the packing of equipment in regards to (1) accessibility, (2) ease of movement, and (3) optimum functioning of measurement devices in the field. Equipment should be packed under the assumption that it will receive severe treatment during shipping and field operation.

3.2.1 Type S Pitot Tube - Pack the pitot tube in a case protected by styrofoam or other suitable packing material. The case should have handles which can withstand hoisting and should be rigid enough to prevent bending or twisting of the pitot tube during shipping and handling.

3.2.2 Differential Pressure Gauge - Close all valves on the pressure gauge and pack it in a suitable case for shipment. Pack spare parts such as O-rings and operating fluid (for inclined manometer).

3.2.3 Temperature Measurement System - Proper packing of the temperature measuring systems depends on the type of system used. In general, the sensor and leads can be protected from breakage or other damage during shipment by securing them to the pitot tube and enclosing them with suitable packing material. The readout device, if detachable from the sensor, should be packed in a separate packing case. Check batteries and include spares prior to shipment if applicable.

3.2.4 Barometer - The barometer should be packed in a shock-mounted (spring system) carrying case.

Table 3.1  ACTIVITY MATRIX FOR PRE-SAMPLING

| Operation | Acceptance limits | Frequency and method of measurement | Action if requirements are not met |
|---|---|---|---|
| Type S pitot tube assembly | 1.  No evidence of damage/misalignment | 1.  Visually check for damage, alignment | 1.  Replace or repair, and then recalibrate |
| | 2.  Proper operation | 2.  Check quick disconnects for proper operation | 2.  Clean, and use a drop of penetrating oil |
| | 3.  Cleaned according to procedure | 3.  Blow out tube legs; rinse first with distilled $H_2O$ and then with acetone; dry with compressed air | Reclean |
| | 4.  No leaks | 4.  Check for leaks | 4.  Repair or replace as necessary |
| | 5.  No visual damage or leaks | 5.  Visually check differential pressure gauge for damage or leaks | 5.  Repair or replace as necessary |
| | 6.  Proper response of the gauge | 6.  Check for obstruction by blowing lightly | 6.  Remove obstruction, and repeat test |
| | 7.  Sensitivity $\pm1.3$ mm (0.05 in.) $H_2O$ | 7.  Check reservoir for proper adjustment range | 7.  Add or remove fluid |
| Temperature measurement system | Agreement within $\pm4°C$ (7°F) (<1.5% at 293K) (530°R); $\sim$ room temperature | Before each field test, compare absolute ambient readings to those with a Hg-in-glass thermometer | Recalibrate the system |

(continued)

Table 3.1 (continued)

| Operation | Acceptance limits | Frequency and method of measurement | Action if requirements are not met |
|---|---|---|---|
| Barometer | Agreement within (2.5 mm) 0.1 in. Hg | Before each field test, check against a Hg barometer | Adjust until agreement attained |
| Packing equipment for shipment | Packed according to specified conditions | Visually check | Correct the packing procedure |

## 4.0 ON-SITE MEASUREMENTS

The on-site measurement activities include transporting equipment to the test site, unpacking and assembling equipment, making duct measurements, measuring velocity, determining molecular weight, and recording data. Table 4.1 at the end of this section summarizes the quality assurance activities for on-site measurements. A copy of all field data forms mentioned are in Section 3.1.12.

### 4.1 Transport of Equipment to the Sampling Site

The most efficient means of transporting the equipment from ground level to the sampling site should be decided during the preliminary site visit (or prior correspondence). Care should be exercised to prevent damage to the test equipment or injury to test personnel during the moving phase.

### 4.2 Velocity Measurement

On-site measurements include the following steps:

1. Preliminary measurements and setup; this includes a determination of acceptable flow conditions, as described in Method 1 (Section 3.0.1).

2. Leak checking the pitot tube and differential pressure gauge.

3. Insertion of the pitot assembly into the stack.

4. Sealing the port.

5. Measuring velocity pressure and temperature at designated points.

6. Measuring the static pressure of the stack.

7. Determining the moisture content according to Method 4.

8. Determining the molecular weight according to Method 3.

A final leak check of the pitot tube and differential pressure gauge assembly must always be performed upon completion of sampling. Record all data on Figure 4.1 or similar form.

| Plant and city | Run date |
|---|---|
| Valley Power Co, Thornville, Ohio | 0 1 1 5 8 0 |

| Sampling location | Clock time 9 50 |
|---|---|
| Main Stock | |

| Run number | Operator | Amb. temp., °F | Bar. press., in. Hg | Static press., in. $H_2O$ |
|---|---|---|---|---|
| 1 | B Blason | 79 | 29.54 | −0.05 |

| Molecular wt. | Stack inside dimension, in. | | Pitot tube ($C_p$) |
|---|---|---|---|
| | Diam. of side 1 | side 2 | |
| 3 0 . 2 5 | 4 8 | | 0 . 8 4 |

**Field data**

| Traverse point number | Position, in. | Velocity head ($\Delta p_s$), in. $H_2O$ | Stack temp., °F | Cyclonic flow determination | |
|---|---|---|---|---|---|
| | | | | $\Delta p_s$ at 0° reference | Angle ($\alpha$) which yields a null $\Delta p$ |
| A) 1 | 2.1 | 1.0 | 287 | 0.1 | 1 |
| 2 | 7.0 | 1.1 | 287 | 0.3 | 2 |
| 3 | 12.2 | 1.2 | 287 | 0.5 | 3 |
| 4 | 33.8 | 1.2 | 288 | 0.5 | 3 |
| 5 | 41.0 | 1.2 | 288 | 0.7 | 5 |
| 6 | 45.9 | 1.1 | 288 | 0.6 | 5 |
| | | | | | |
| B) 1 | 2.1 | 1.2 | 288 | 0.1 | 1 |
| 2 | 7.0 | 1.2 | 288 | 0.1 | 1 |
| 3 | 12.2 | 1.3 | 288 | 0.3 | 2 |
| 4 | 33.8 | 1.3 | 288 | 0.5 | 4 |
| 5 | 41.0 | 1.2 | 287 | 0.5 | 5 |
| 6 | 45.9 | 1.1 | 287 | 0.5 | 5 |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

| | Average angle ($\alpha$)[a] | 3 |
|---|---|---|

[a] Average of $\alpha$ must be <10 degrees to be acceptable.

Figure 4.1   Method 2 gas velocity and volume data form.

4.2.1 <u>Preliminary Measurements and Setup</u> - An accurate determination of the stack's cross-sectional area is important when calculating volumetric flow rate. Also, the inside dimensions must be known to properly mark the pitot tube for making a velocity traverse and to calculate a total flow rate. Field team members must use good judgement and experience in selecting the best method of measuring stack dimensions for each particular situation.

Two commonly used methods of measuring stack dimensions are:

1. Inserting a rigid rod made of metal or other material that will, in most instances, withstand stack conditions through a sampling port, is the easiest and most accurate method of measuring the dimensions (i.e., diameter or length and width) of small stacks . <u>Caution</u>: When testing a stack that has hot and/or noxious gases at a positive pressure, use a packing gland to prevent the gases from escaping from the sampling port. Also, wear asbestos gloves when working around a hot stack.

Because all circular stacks are not perfect circles and because all sides of a rectangular stack are not straight, best results are obtained if the dimensions are measured from as many sampling ports as available at the sampling site. Calculate the average value for use in subsequent calculation of the volumetric flow rate. Sketch the cross-sectional area of the stack on the sample data form (Figure 4.1), and show all measured dimensions and their values. Record the average value on the same form in the blank space designated for stack dimension. (If the stack is rectangular, record the average length and width in this space, and mark out the diameter.) Determine all dimensions to the nearest 3 mm (1/8 in.).

2. For stacks too large or too inconvenient for measuring with a rod as described in (1) above, the next best method may be to measure the outside circumference and to calculate the inside diameter (d):

$$d = (C/\pi) - 2t \qquad \text{Equation 4-1}$$

where

    d = inside diameter of the stack,

    C = outside circumference of stack,

    $\pi \simeq 3.1416 \simeq 22/7$, and

    t = stack wall thickness.

For rectangular stacks, measure the outside dimensions and subtract the (2t) wall thickness; measure all lengths to the nearest 3 mm (1/8 in). <u>Note</u>: In horizontal ducts, particulate buildup may occur on the bottom of the duct; this buildup (determined visually or by probing with a rod) should be subtracted from the duct cross section. Select the sampling site location in accordance with Method 2; if this is not possible due to duct configuration or other reasons, have the sampling site location approved by the administrator. Determine the minimum number of traverse points by Method 1, or check the traverse points determined from the preliminary site visit (Section 3.0 of this Handbook). Record all data on the traverse point location form, as shown in Section 3.0. Use these measurements to locate the pitot tube and the sampling probe during preliminary measurements and actual sampling.

4.2.2 <u>Stack Parameters</u> - Check the sampling site for cyclonic or nonparallel flow, as described in Method 1 (Section 3.0.1). The sampling site must be acceptable before a valid measurement can be made. Be sure that the proper differential pressure gauge is chosen for the range of velocity heads encountered.

4.2.3 <u>Velocity Measurement</u> - Determine the number and location of traverse points and sampling ports by Method 1. For circular stacks <3 m (10 ft) in diameter, two ports along diameters at right angles to each other and in the same plane are sufficient; however, when the stack diameter is >3 m (10 ft), four ports--one at each end of the two diameters--are desirable to avoid the use of extra long pitot tubes. If it is necessary to use a Type S pitot tube >3 m (10 ft) in length, it should be structurally reinforced to prevent bending of the tube and resulting in the type

error illustrated in Figure 2.7. Each sampling port and traverse point should be identified by a number or letter and should be so-designated on the sketch.

Measure the velocity head and temperature at each traverse point accessible from a given port by measuring each point once as the pitot tube is inserted into the stack and moved across the stack's diameter. To prevent damage or clogging, be careful to avoid touching the pitot tube tip to the side of the stack wall.

A standard pitot tube may be used instead of a Type S, for conducting velocity traverses; however, the static and impact pressure holes of standard pitot tubes are susceptible to plugging in particulate-laden or moist gas streams. Therefore, whenever a standard pitot tube is used to perform a traverse, adequate proof must be furnished to show that the openings of the pitot tube did not plug up during the traverse period.

The following procedure will provide sufficient evidence that plugging did not occur.

1. Measure the velocity head ($\Delta p$) reading at the final traverse point.

2. Clean out the impact and static holes of the standard pitot tube by "back purging" with pressurized air, and then re-measure the $\Delta p$ at the final point. If the $\Delta p$ readings before and after the air purge are the same ($\pm 5\%$), the traverse is acceptable. Note: If $\Delta p$ at the final point is unsuitably low, another point may be selected.

If "back purging" at regular intervals is part of the procedure, comparative $\Delta p$ readings should be taken (as above) for the last two back purges at which suitably high $\Delta p$ readings are observed.

3. Record the clock time, $\Delta p$, and $T_s$ for each traverse point on the data form (Figure 4.1).

4. After the traverse, check the differential pressure gauge zero setting and local indicator. If either has shifted, reset and repeat the traverse.

If a more sensitive differential pressure gauge is required after making a traverse because the velocity head readings were <1.3 mm (0.05 in.), use a more sensitive manometer, as discussed in Section 3.1.1.  After completing the traverse, check the pitot tube differential pressue gauge assembly again for leaks, as described in Subsection 4.2.5.

4.2.4  <u>Measurement of Low Velocities</u> - A Type S pitot tube can be used to measure velocities as low as 122 m/min (400 ft/min) without affecting the calibration coefficient.

Most sampling trains are equipped with a 10-in. ($H_2O$ column) inclined vertical manometer that has 0.01-in. divisions on the 0-to-1-in. inclined scale and 0.1-in. divisions on the 1-to-10-in. vertical scale.  This type of manometer (or other gauge of equivalent sensitivity) is satisfactory for the measurement of $\Delta p$ values as low as 1.3 mm (0.05 in.) $H_2O$.  However, a differential pressure gauge of greater sensitivity should be used (subject to the approval of the administrator) if any of the following is found to be true:

1.   The arithmetic average of all $\Delta p$ readings at the traverse points in the stack is <1.3 mm (0.05 in.) $H_2O$;

2.   More than 10% of the individual $\Delta p$ readings are <1.3 mm (0.05 in.) $H_2O$ points, for traverses of 12 or more points;

3.   More than one $\Delta p$ reading is <1.3 mm (0.05 in.) $H_2O$ for traverses of fewer than 12 points.

As an alternative to criteria (1) through (3) above, the following calculation may be performed to determine the necessity of using a more sensitive differential pressure gauge:

$$T = \frac{\sum\limits_{i=1}^{n} \sqrt{\Delta p_i + K}}{\sum\limits_{i=1}^{n} \sqrt{\Delta p_i}}$$

where

$\Delta p_i$ = individual velocity head reading at a traverse point, mm (in.) $H_2O$,

n = total number of traverse points, and

K = 0.13 mm (0.005 in.) $H_2O$.

If T is >1.05, the velocity head data are unacceptable, and a more sensitive differential pressure gauge must be used.

4.2.5  <u>Special Precautions</u> - Before and during the traverse, a number of precautions should be taken:

1.  The pitot tube should be short enough for easy handling from outside the stack when held at any traverse point for safety reasons and for efficiency in the measurement process.

2.  The alignment should be made visually with reference to the stack geometry and not by rolling or tipping the pitot tube until a maximum response is observed.

3.  If the gas stream contains a significant concentration of particulates, both legs of the pitot tube should be blown out frequently during the velocity traverse.

4.  All unused sampling ports must be plugged, and the port being used should be sealed as tightly as possible to minimize any disturbance on the gas flow pattern when making a velocity measurement.  The port being used can be sealed with asbestos material, precut sponge, or duct tape depending on the temperature of the stack gas.

5.  If liquid droplets are present in the gas stream, a liquid trap should be inserted in the gauge line leading to the upstream pitot tube leg (impact opening).  A trap may be required for both legs.

6.  When testing a stack that has hot and/or noxious gases under positive pressure, a packing gland and gate valve assembly should be used to prevent the gases from escaping from the sampling port.  Caution:  Asbestos gloves should be worn when working around a hot stack.  Always wear safety glasses and under hazardous conditions, fullface shields.

7. Damage or suspected damage to any item of equipment, such as a pitot tube or an inclined manometer, during the test should be fully documented at the time it occurs or at the first awareness of its occurrence. The item should be replaced by a spare if available. If it is necessary to continue using the damaged item, a posttest calibration (as described in Section 3.1.2) should be performed, and the new calibration should be used for the data collected after the damage occurred.

4.2.6 <u>Measurement of the Static Pressure in the Stack</u> - Three acceptable methods for measuring static pressure are given in the order of decreasing acceptability:

1. Install a tap perpendicular to the stack gas flow, or insert a 6-mm (0.25-in.) steel tube into the sampling port while maintaining a good seal. Connect one side of a U-tube manometer to the tap, and vent the other side of the manometer to the atmosphere. If the pressure is expected to be >63-75 cm (25-30 in.) $H_2O$, a mercury-filled U-tube manometer should be used instead of a water-filled U-tube.

2. Use the static pressure tap of a standard pitot tube connected to one side of a manometer. (If the stack pressure is obviously negative, connect the static pressure tap to the other side of the manometer; otherwise trial and error will have to suffice.) Vent the remaining side of the manometer to the atmosphere. Point the pitot tube pressure opening (the unconnected end) directly into the flow and seal the port around the tube.

3. Use a Type S pitot tube with the pitot tube openings facing perpendicular to the gas stream. Connect only one leg of the pitot tube to the manometer; vent the other side of the manometer to the atmosphere. Take extreme care to align the probe properly and to seal the port around the pitot tube.

One static pressure reading is usually adequate for all points within a stack; however, this must be confirmed by randomly moving the pressure probe over the stack to see if there are any significant variations--that is, a range of pressure

values >100 mm (4 in.) $H_2O$. If there are significant variations, visually check the location for physical flow disturbances. If none are found, measure and record the static pressure at each traverse point.

4.  Measure the atmospheric pressure at the test site using the barometer.

Record the static pressure, $P_g$, (be sure to include the plus or minus sign for positive or negative pressure respectively) as read from the manometer on the velocity data form, Figure 4.1.

4.2.7  <u>Pitot Tube Calibration Check</u> - If the pitot tube coefficient were based on an acceptable geometry standard, be sure that the pitot meets these standards prior to each run and that no posttest data correction is required from any pitot tube damages that may have occurred during testing.

4.2.8  <u>Dry Stack Gas Molecular Weight Determination</u> - For combustion processes, use Method 3. For processes emitting essentially air, an analysis need not be conducted and a molecular weight of 29 should be used. Moisture content can be measured by using Method 4. For other processes, consult the administrator.

4.3  <u>Sample Logistics (Data) and Packing of Equipment</u> - Follow the above procedures until the required number of runs are completed. Log all data on the form shown previously in Figure 4.1.

The following are recommended at the completion of the test series:

1.  Record and duplicate all data recorded during the field test by the best means available. One set of data can then be either mailed to the base laboratory, given to another team member, or to the Agency; the original data should be hand-carried.

2.  Examine all sampling equipment for damage, and then properly pack it for shipment to the base laboratory. All shipping containers should be properly labeled to prevent loss of equipment.

3.  Quickly check sampling procedures using the data form, Figure 4.2.

Sampling

Pitot tube, lines, and manometer assembled correctly?* ___YES___

Pitot tube and components mounted in an interference free man-
ner?* _____YES_____

Differential pressure gauge has correct sensitivity?* ___YES___

Differential pressure gauge leveled and zeroed?* _____YES___

Pretest leak check? _YES_ (optional)  Cyclonic flow checked? _YES_

Pitot tube parallel to stack walls?* _____YES_____

Static pressure measured? _YES_  Temperature measured? _YES_

Moisture content determined? ___YES___  Method _REFERENCE METHOD 4_

Orsat samples taken? ___YES___  If no explain: _____

_____

Posttest leak check performed?* _____YES_____ (mandatory)

Data recorded properly? _____YES_____

*Most significant items/parameters to be checked.

Figure 4.2  On-site measurements checklist.

Table 4.1   ACTIVITY MATRIX FOR ON-SITE MEASUREMENTS

| Activity | Acceptance limits | Frequency and method of measurement | Action if requirements are not met |
|---|---|---|---|
| Type S pitot tube and differential pressure gauge | Leak-free connections; manometer properly leveled; oil column zeroed | Visually check before taking measurements at each field test | Take corrective action |
| Temperature measurement system | No physical damage | Visually check for damage | Take corrective action prior to taking measurements |
| Cross sectional area of stack | All measurements made to the nearest 3 mm (1/8 in.) | During each field test, measure inside diameter (or width) and/or circumference (perimeter) | Obtain data as specified |
| Velocity measurements | 1.  Number and location of traverse points (Method 1)<br><br>2.  No leaks for 15 s | 1.  Check before taking measurements<br><br>2.  Apparatus leak checked upon completion of tests | Repeat traverse |
| Static pressure | Variation in static pressure Pg <100 mm (3.9 in.) $H_2O$ to make a single point measurement | Use one of three means given in Subsec 4.8; move probe over cross section to determine if variation is significant | Check the location for disturbances; if none, measure and record the static pressure at each point |

(continued)

Table 4.1 (continued)

| Activity | Acceptance limits | Frequency and method of measurement | Action if requirements are not met |
|----------|-------------------|-------------------------------------|-------------------------------------|
| Sample logistics (data) and packing of equipment | 1. All data recorded correctly | 1. Upon completion of each traverse and before packing for shipment | 1. Complete required number of runs |
| | 2. All equipment examined for damage and labeled for shipment | 2. As above | 2. Repeat the sampling if damage occurred during testing |

5.0  POSTSAMPLING OPERATIONS

Table 5.1 at the end of this section summarizes the quality assurance activities for postsampling operations.

5.1  Apparatus Checks

Disassemble, clean, and visually check each component of the sample apparatus upon completion of sampling. Posttest calibration must be performed on the pitot tube if damaged, and the temperature sensor.

5.1.1  Pitot Tube - If the pitot tube is damaged, do not repair if the sample runs were started with the unacceptable pitot tube. Calibrate the pitot tube according to Section 3.1.2. For calibration purposes, the pitot tube posttest coefficient should be used for all data obtained using the damaged pitot tube only. For any runs that started with an acceptable pitot tube no data correction is required. After calibration, repair the pitot tube and calibrate as initially (by dimensional specifications or calibration). Record posttest calibration data on Figure 5.1. If all runs were started with an acceptable pitot, and repairs can be made, no field data correction is required.

5.1.2  Temperature Sensor - The stack temperature sensor readings should be compared with the reference thermometer readings.

For thermocouples(s), compare the thermocouple and reference thermometer values at ambient temperature. If the values agree within ±1.5% of the absolute temperature, the calibration is considered valid. If the values do not agree within ±1.5%, recalibrate the thermocouple as described in Section 3.1.2 to determine the difference ($\Delta T_s$) at the average stack temperature ($T_s$). Note: This comparison may be done in the field immediately following the tests.

For thermometers, compare the reference thermometer (1) at ambient temperatures for average stack temperature below 100°C (212°F), (2) in boiling water for stack temperatures from 100° - 200°C (212° - 390°F), and (3) in a boiling liquid with a boiling

Pitot Tube

Initial pitot tube coefficient _____ *0.84* _____
Was pitot tube damaged prior to start of any test runs? ____ yes
  ✓ no
  If yes, was pitot tube calibrated prior to repair?* __yes ___no
Pitot tube coefficient (damaged) _____ (this value must
  be used for runs started with the damaged pitot tube)

Temperature Sensor

Was a pretest temperature correction used? _____ yes ✓ no
  If yes, temperature correction _____ °C (°F) (within 1.5%
  of readings in K (°R) over range)
Average stack temperature of compliance test ($T_s$) _*612*_ K (°R)
Temperature of reference thermometer or solution for recalibra-
  tion* _*528*_ K (°R)
Temperature of stack thermometer for recalibration _*523*_ K (°R)
Difference between reference and stack thermometer temperatures
  ($\Delta T_s$) _*5*_ K (°R)
Do values agree within ±1.5%?* _____ ✓ yes _____ no
  If yes, no correction necessary for calculations
  If no, calculations must be done twice, once with recorded,
  values and once with average stack temperature corrected to
  correspond to reference temperature differential ($\Delta T_s$). Both
  values of final results must then be reported since there is no
  way to determine which is correct

Barometer

Was pretest field barometer reading correct? ✓ yes _____ no
Posttest comparison *29.61* mm (in.) (Hg within (±5.0 mm (0.2 in.)
  Hg) of mercury-in-glass barometer)
Was recalibration required? _____ yes ✓ no
  If yes, no correction needed when field barometer has the lower
  reading
  If mercury-in-glass reading is lower, subtract the difference
  from the field data readings for the calculations

*Most significant items/parameters to be checked.

Figure 5.1  Posttest sampling checks.

point >200° (390°F) for stack temperatures between 200° - 405°C
(390° - 760°F).  For stack temperatures >405° (760°F), compare
the stack thermometer with a thermocouple at a temperature with-
in ±10% of the average absolute stack temperature.  If the abso-
lute values agree within ±1.5%, the calibration is considered
valid.  If not, determine the error $(\Delta T_s)$ to correct the average
stack temperature.

5.1.3  Barometer - The field barometers are acceptable if they
agree within ±5 mm (0.2 in.) Hg when compared with the mercury-
in-glass barometer.  When the comparison is not within this
range, the lesser calibration value should be used for the cal-
culations.  If the field barometer reads lower, no correction is
necessary.  When the mercury-in-glass barometer gives the lower
reading, subtract the difference from the field data readings
for the calculations.

Table 5.1  ACTIVITY MATRIX FOR POST-SAMPLING OPERATIONS

| Apparatus | Acceptance limits | Frequency and method of measurement | Action if requirements are not met |
|---|---|---|---|
| Pitot tube | If damaged, recali-brate according to Sec 3.1.2 | After every field test, visually inspect for damage | Recalibrate, and use cali-bration fac-tor for data obtained by using damaged pitot tube or repeat the tests |
| Temperature sensor | Within ±1.5% of absolute temperature | Calibrate with ASTM mercury-in-glass thermometer | Use correc-tion factor on tempera-ture data |
| Barometer | Within ±2.5 mm (0.1 in.) Hg at ambient pressure | Compare with mercury-in-glass barometer after each test | Recalibrate, and use lower barometric values for calculations |

## 6.0 CALCULATIONS

Calculation errors due to procedural or mathematical mistakes can be a large part of total system error. Therefore, it is recommended that each set of calculations be repeated or spot checked, preferably by a team member other than the one who performed the original calculations. If a difference greater than typical roundoff error is detected, the calculations should be checked step-by-step until the source of error is found and corrected. A computer program that prints the input data so that it can be checked is advantageous in reducing calculation errors. If a standardized computer program is used, the original data entry should be checked; if differences are observed, a new computer run should be made. Table 6.1 at the end of this section summarizes the quality assurance activities for calculations.

Calculations should be carried out retaining at least one significant digit beyond that of the acquired data and then should be rounded off after final calculation to two significant digits for each run or sample. All rounding off of numbers should be in accordance with the ASTM 380-76 procedures. Record all calculations on Figures 6.1A or B and on Figures 6.2A or B, or on similar forms.

### 6.1 Nomenclature

The nomenclature used in the calculations that follow are listed alphabetically.

$A$ = Cross-sectional area of stack, $m^2$ ($ft^2$)

$B_{ws}$ = Water vapor in the gas stream (Method 5 or Method 4), proportion by volume

$C_p$ = Pitot tube coefficient, dimensionless

$K_p$ = Pitot tube constant,

$$34.97 \ \frac{m}{s} \ \left[\frac{(g/g\text{-mole})(mm \ Hg)}{(°K)(mm \ H_2O)}\right]^{1/2} \ \text{for the metric system, and}$$

$$85.49 \ \frac{ft}{s} \ \left[\frac{(lb/lb\text{-mole})(in. \ Hg)}{(°R)(in. \ H_2O)}\right]^{1/2} \ \text{for the English system}$$

$M_d$ = Molecular weight of stack gas, dry basis, g/g-mole (lb/lb-mole)

$M_s$ = Molecular weight of stack gas, wet basis, g/g-mole (lb/lb-mole), or

$\qquad M_d(1 - B_{ws}) + 18.0 \ B_{ws}$              Equation 6-1

$\Delta p$ = Velocity head of stack gas, mm (in.) $H_2O$

$P_{bar}$ = Barometric pressure at measurement site, mm (in.) Hg

$P_g$ = Stack static pressure, mm (in.) Hg

$P_s$ = Absolute stack gas pressure, mm (in.) Hg, or

$\qquad P_{bar} + P_g$                                Equation 6-2

$P_{std}$ = Standard absolute pressure, 760 mm (29.92 in.) Hg

$Q_{std}$ = Dry volumetric stack gas flow rate corrected to standard conditions, dsm$^3$/h (dscf/h)

$t_s$ = Stack temperature, °C (°F)

$T_s$ = Absolute stack temperature, K (°R), or

$\qquad 273 + t_s$ for metric system           Equation 6-3

$\qquad 460 + t_s$ for English system         Equation 6-4

$T_{std}$ = Standard absolute temperature, 293K (528°R)

$v_s$ = Average stack gas velocity, m/s (ft/s)

3600 = Conversion factor, s/h

18.0 = Molecular weight of water, g/g-mole (lb/lb-mole)

## 6.2 Calculations

The following are the equations used to calculate the stack gas velocity and the volumetric flow rate.

6.2.1 <u>Average Stack Gas Velocity</u> - Equation 6-5 is used to calculate the average stack gas velocity at stack conditions.

$$v_s = K_p C_p \, (\sqrt{\Delta p})_{avg} \sqrt{\frac{(T_s)_{avg}}{P_s M_s}} \qquad \text{Equation 6-5}$$

This equation assumes that $T_s$, $P_s$, and $M_s$ do not change appreciably (i.e., <1%) with cross-sectional distance and with time. If they do, consult the administrator to determine an acceptable procedure.

The $(\sqrt{\Delta p})$avg term is the average square root of each individual velocity head ($\Delta p$). Additionally, it should be noted here that to be technically correct the term $(\sqrt{T_s})_{avg}$ should be used. However, since $T_s$ is large, (usually $\geq$289K (515°R), the term $\sqrt{(T_s)_{avg}}$ can be used with <1% error if the range of $t_s$ is not $\geq$10°C (50°F).

6.2.2 <u>Average Stack Gas Dry Volumetric Flow Rate</u> - Calculate $Q_{std}$ using Equation 6-6,

$$Q_{std} = 3600(1 - B_{ws})v_s \, A \left(\frac{T_{std}}{(T_s)_{avg}}\right)\left(\frac{P_s}{P_{std}}\right) \qquad \text{Equation 6-6}$$

Table 6.1   ACTIVITY MATRIX FOR CALCULATION CHECKS

| Characteristice | Acceptance limits | Frequency and method of measurement | Action if requirements are not met |
|---|---|---|---|
| Data analysis form | All data and calculations given | Visually check | Complete the missing data values |
| Calculations | Difference between check and original calculations within round-off error; at least one decimal figure retained beyond that of acquired data | Repeat all calculations, starting with raw data for hand calculations; check all raw data input to computer calculations; hand calculate one sample per test | Indicate errors on analysis data form |

7.0  MAINTENANCE

The normal use of emission testing equipment subjects it to corrosive gases, extremes in temperature, vibrations, and shocks. Keeping the equipment in good operating order over an extended period of time requires a knowledge of the equipment and a program of routine maintenance which is performed quarterly. Maintenance procedures for the various components are summarized in Table 7.1 below.

The following procedures are not required, but are recommended to increase the reliability of the equipment.

7.1  Pitot Tube

The pitot tube should be checked for dents, corrosion, and dirt that may cause a complete restriction of pressure or cause a leak in the system.

7.2  Inclined Manometer

The fluid in the inclined manometer should be changed whenever there is discoloration or visible matter in the fluid, and during the yearly disassembly. No other routine maintenance is required since the inclined manometers will be leak checked during both the leak check of the pitot tube and the leak check of the entire control console.

Table 7.1  ACTIVITY MATRIX FOR EQUIPMENT MAINTENANCE CHECKS

| Apparatus | Acceptance limits | Frequency and method of measurement | Action if requirements are not met |
|---|---|---|---|
| Pitot tube | Check for dents, corrosion, other damage, or broken welds | Visually check before and after each test run | Use another pitot tube or clean, repair, and calibrate |
| Inclined manometer | No discoloration or visible matter in the fluid | Check periodically during disassembly | Replace parts as needed |

## 8.0  AUDITING PROCEDURE

An audit is an independent assessment of data quality. Independence is achieved if the individual(s) performing the audit and their standards and equipment are different from those used by the regular field crew. Routine quality assurance checks by a field team are necessary in generation of good quality data, but they are not part of the auditing procedure. Table 8.1 at the end of this section summarizes the quality assurance activities for auditing, and Figure 8.1 suggest a checklist for the auditor.

Based on the results of a collaborative test of Method 2,[2] two specific performance audits are recommended:

1.    Audit of the measurement phase of Method 2, and

2.    Audit of data processing.

In addition to these performance audits, a systems audit may be conducted as specified by the quality assurance coordinator. The performance audits and the systems audit are described in Subsections 8.1 and 8.2, respectively.

### 8.1  Performance Audits

Performance audits quantitatively evaluate the quality of data produced by the total measurement system (sample collection, data processing, etc.). It is recommended that these audits be performed by the responsible control agency once during every enforcement source test. A source test for enforcement comprises a series of runs at one source.

8.1.1  Audit of Measurement Systems - A performance audit should be performed on the geometric standards for the Type S pitot tube, as described in Section 3.1.1.

8.1.2  Audit of Data Processing - Calculation errors are prevalent in Method 2. Data processing errors can be determined by auditing the data recorded on the field and laboratory forms.

The original and audit (check) calculations should agree within roundoff; if not, all of the remaining data should be checked. The data processing may also be audited by providing the testing laboratory with specific data sets (exactly as would occur in the field) and by requesting that the data calculation be completed and that the results be returned to the agency/organization. This audit is useful in checking both computer programs and manual methods of data processing.

8.2 Systems Audit

A systems audit is an on-site qualitative inspection and review of the total measurement system (sample collection, data processing, etc.). Initially, a systems audit is recommended for each enforcement source test, defined here as a series of three runs at one source. After the test team gains experience with the method, the frequency of audit may be reduced--once for every four tests.

The auditor should have extensive background experience in source sampling, specifically with the measurement system being audited. The functions of the auditor are summarized in the following:

1. Inform the testing team of the results of pretest audits, specifying any area(s) that need special attention or improvement.

2. Observe procedures and techniques of the field team during sample collection.

3. Check/verify records of apparatus calibration checks from previous source tests, where applicable.

4. Record the results of the audit and forward them with comments to the team management so that appropriate corrective action may be initiated.

While on site, the auditor observes the source test team's overall performance including the following specific operations:

1. Determining stack dimensions and selecting the number and position of traverse points.

2.    Checking the geometry criteria in the field using the devices described in the calibration section.

3.    Marking the pitot tube to ensure measurements at the correct traverse points.

4.    Checking for cyclonic flow.

5.    Aligning the pitot tube properly along its roll and pitch axes throughout the velocity traverse.

6.    Clearing the pitot tube frequently when measuring in a dust-laden gas.

7.    Leak checking the sample apparatus.

| Yes | No | Operation |
|-----|-----|-----------|
| | | **Presampling preparation** |
| ✓ | | 1. Knowledge of process conditions |
| ✓ | | 2. Calibration of pertinent equipment prior to each field tests |
| | | **On-site measurements** |
| ✓ | | 3. Pitot tube meets geometry requirements |
| ✓ | | 4. Manometer should be carefully leveled and the liquid column set exactly on zero |
| ✓ | | 5. Check for cyclonic flow |
| ✓ | | 6. Leak check after sample run |
| ✓ | | 7. Sampling port adequately plugged |
| ✓ | | 8. Process at correct operating level |
| ✓ | | 9. Pitot tube properly aligned along its roll and pitch axes throughout the traverse |
| ✓ | | 10. Pitot tube frequently cleared when measuring in a dust-laden gas |
| ✓ | | 11. Manometer has the correct sensitivity |
| ✓ | | 12. Staying at each traverse point long enough for the system to stabilize |
| ✓ | | 13. Measuring the stack gas static pressure and temperature |
| | | **Postsampling** |
| ✓ | | 14. All information recorded on data form as obtained |
| ✓ | | 15. Any unusual conditions recorded |
| ✓ | | 16. Independent check of calculations |
| ✓ | | 17. Temperature sensor calibrated |
| COMMENTS | | |
| | | |

Figure 8.1 Stack gas velocity and volumetric flow rate determination checklist to be used by auditor.

Table 8.1   ACTIVITY MATRIX FOR AUDITING PROCEDURE

| Audit | Acceptance limits | Frequency and method of measurement | Action if requirements are not met |
|---|---|---|---|
| Data processing errors | Original and check calculations agree within roundoff error | Once during every enforcement source test, perform independent calculations, starting with recorded data | Check and correct all data for the source test |
| Systems audit | Operation technique described in this section of the Handbook | Once during every enforcement test until experience gained; then every fourth test; observation of technique, assisted by audit checklist, Fig 8.1 | Explain to team its deviations from recommended techniques, and note on Fig 8.1 |

## 9.0 RECOMMENDED STANDARDS FOR ESTABLISHING TRACEABILITY

To achieve data of desired quality, two considerations are necessary: (1) the measurement process must be in a state of statistical control at the time of the measurement, and (2) the systematic errors, when combined with the random variation (errors of measurement), must result in a small uncertainty.

To ensure good quality data, it is necessary to perform quality control checks and independent audits of the measurement process; to document these checks and audits by recording the results, as appropriate; and to use materials, instruments, and measurement procedures that can be traced to an appropriate standard of reference.

Working calibration standards should be traceable to standards that are considered to be primary. Two primary standards recommended for establishing traceability are:

1. Calibrate pitot tubes against a standard pitot tube with a known coefficient obtained from the National Bureau of Standards or standard measurement which has been shown to have given acceptable coefficients.

2. Compare the stack temperature sensor to an ASTM reference thermometer.

## 10.0   REFERENCE METHOD[*]

### METHOD 2—DETERMINATION OF STACK GAS VELOCITY AND VOLUMETRIC FLOW RATE (TYPE S PITOT TUBE)

#### 1. *Principle and Applicability*

1.1  Principle. The average gas velocity in a stack is determined from the gas density and from measurement of the average velocity head with a Type S (Stausscheibe or reverse type) pitot tube.

1.2  Applicability. This method is applicable for measurement of the average velocity of a gas stream and for quantifying gas flow.

This procedure is not applicable at measurement sites which fail to meet the criteria of Method 1, Section 2.1. Also, the method cannot be used for direct measurement in cyclonic or swirling gas streams; Section 2.4 of Method 1 shows how to determine cyclonic or swirling flow conditions. When unacceptable conditions exist, alternative procedures, subject to the approval of the Administrator, U.S. Environmental Protection Agency, must be employed to make accurate flow rate determinations; examples of such alternative procedures are: (1) to install straightening vanes; (2) to calculate the total volumetric flow rate stoichiometrically, or (3) to move to another measurement site at which the flow is acceptable.

#### 2. *Apparatus*

Specifications for the apparatus are given below. Any other apparatus that has been demonstrated (subject to approval of the Administrator) to be capable of meeting the specifications will be considered acceptable.

---

1.90 - 2.54 cm*
(0.75 - 1.0 in.)

7.62 cm (3 in.)*

**TEMPERATURE SENSOR**

**TYPE S PITOT TUBE**

**LEAK-FREE CONNECTIONS**

**MANOMETER**

*SUGGESTED (INTERFERENCE FREE)
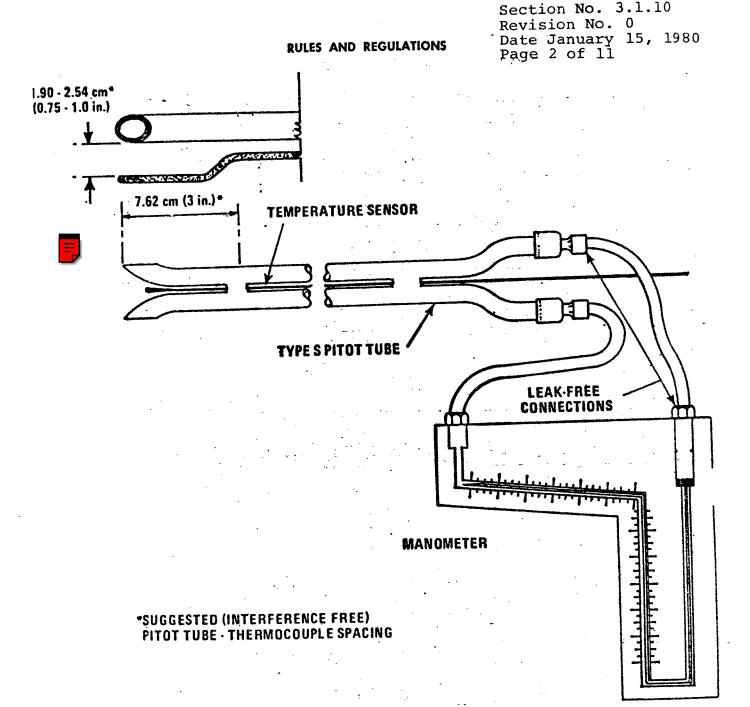PITOT TUBE · THERMOCOUPLE SPACING

**Figure 2-1. Type S pitot tube manometer assembly.**

2.1 Type S Pitot Tube. The Type S pitot tube (Figure 2-1) shall be made of metal tubing (e.g., stainless steel). It is recommended that the external tubing diameter (dimension $D_t$, Figure 2-2b) be between 0.48 and 0.95 centimeters (3/16 and 1/4 inch). There shall be an equal distance from the base of each leg of the pitot tube to its face-opening plane (dimensions $P_A$ and $P_B$, Figure 2-2b); it is recommended that this distance be between 1.05 and 1.50 times the external tubing diameter. The face openings of the pitot tube shall, preferably, be aligned as shown in Figure 2-2; however, slight misalignments of the openings are permissible (see Figure 2-3).

The Type S pitot tube shall have a known coefficient, determined as outlined in Section 4. An identification number shall be assigned to the pitot tube; this number shall be permanently marked or engraved on the body of the tube.
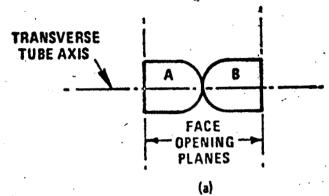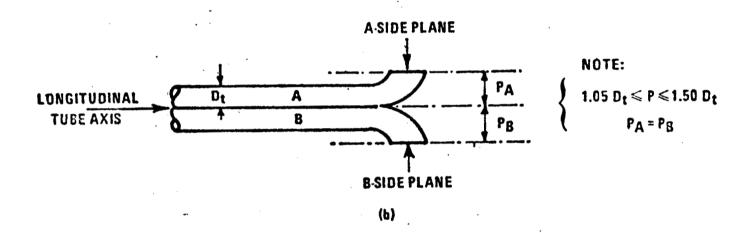
41700

RULES AND REGULATIONS

Section No. 3.1.10
Revision No. 0
Date January 15, 1980
Page 3 of 11

TRANSVERSE
TUBE AXIS

A    B

FACE
OPENING
PLANES

(a)

A-SIDE PLANE

LONGITUDINAL
TUBE AXIS

$D_t$    A

B

$P_A$

$P_B$

B-SIDE PLANE

(b)

NOTE:

$1.05\ D_t \leqslant P \leqslant 1.50\ D_t$

$P_A = P_B$
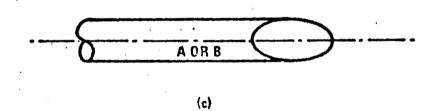
A OR B

(c)

Figure 2-2. Properly constructed Type S pitot tube, shown in: (a) end view; face opening planes perpendicular to transverse axis; (b) top view; face opening planes parallel to longitudinal axis; (c) side view; both legs of equal length and centerlines coincident, when viewed from both sides. Baseline coefficient values of 0.84 may be assigned to pitot tubes constructed this way.
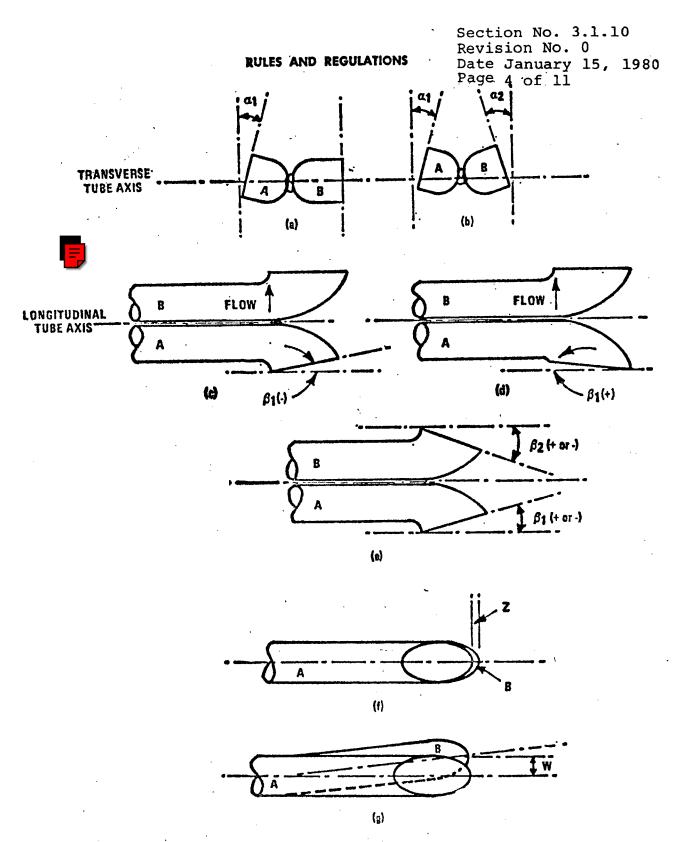
Figure 2-3. Types of face-opening misalignment that can result from field use or improper construction of Type S pitot tubes. These will not affect the baseline value of $\overline{C}p(s)$ so long as $a_1$ and $a_2 < 10^\circ$, $\beta_1$ and $\beta_2 < 5^\circ$. z < 0.32 cm (1/8 in.) and w < 0.08 cm (1/32 in.) (citation 11 in Section 6).

**41762**

**RULES AND REGULATIONS**

Section No. 3.1.10
Revision No. 0
Date January 15, 1980
Page 5 of 11

A standard pitot tube may be used instead of a Type S, provided that it meets the specifications of Sections 2.7 and 4.2; note, however, that the static and impact pressure holes of standard pitot tubes are susceptible to plugging in particulate-laden gas streams. Therefore, whenever a standard pitot tube is used to perform a traverse, adequate proof must be furnished that the openings of the pitot tube have not plugged up during the traverse period; this can be done by taking a velocity head (Δp) reading at the final traverse point, cleaning out the impact and static holes of the standard pitot tube by "back-purging" with pressurized air, and then taking another Δp reading. If the Δp readings made before and after the air purge are the same ( ±5 percent), the traverse is acceptable. Otherwise, reject the run. Note that if Δp at the final traverse point is unsuitably low, another point may be selected. If "back-purging" at regular intervals is part of the procedure, then comparative Δp readings shall be taken, as above, for the last two back purges at which suitably high Δp readings are observed.

2.2 Differential Pressure Gauge. An inclined manometer or equivalent device is used. Most sampling trains are equipped with a 10-in. (water column) inclined-vertical manometer, having 0.01-in. $H_2O$ divisions on the 0- to 1-in. inclined scale, and 0.1-in. $H_2O$ divisions on the 1- to 10-in. vertical scale. This type of manometer (or other gauge of equivalent sensitivity) is satisfactory for the measurement of Δp values as low as 1.3 mm (0.05 in.) $H_2O$. However, a differential pressure gauge of greater sensitivity shall be used (subject to the approval of the Administrator), if any of the following is found to be true: (1) the arithmetic average of all Δp readings at the traverse points in the stack is less than 1.3 mm (0.05 in.) $H_2O$; (2) for traverses of 12 or more points, more than 10 percent of the individual Δp readings are below 1.3 mm (0.05 in.) $H_2O$; (3) for traverses of fewer than 12 points, more than one Δp reading is below 1.3 mm (0.05 in.) $H_2O$. Citation 18 in Section 6 describes commercially available instrumentation for the measurement of low-range gas velocities.

As an alternative to criteria (1) through (3) above, the following calculation may be performed to determine the necessity of using a more sensitive differential pressure gauge:

$$ T = \frac{\sum\limits_{i=1}^{n} \sqrt{\Delta p_i + K}}{\sum\limits_{i=1}^{n} \sqrt{\Delta p_i}} $$

where:

$\Delta p_i$ = Individual velocity head reading at a traverse point, mm $H_2O$ (in. $H_2O$).
$n$ = Total number of traverse points.
$K$ = 0.13 mm $H_2O$ when metric units are used and 0.005 in. $H_2O$ when English units are used.

If $T$ is greater than 1.05, the velocity head data are unacceptable and a more sensitive differential pressure gauge must be used.

Note.—If differential pressure gauges other than inclined manometers are used (e.g., magnehelic gauges), their calibration must be checked after each test series. To check the calibration of a differential pressure gauge, compare Δp readings of the gauge with those of a gauge-oil manometer at a minimum of three points, approximately representing the range of Δp values in the stack. If, at each point, the values of Δp as read by the differential pressure gauge and gauge-oil manometer agree to within 5 percent, the differential pressure gauge shall be considered to be in proper calibration. Otherwise, the test series shall either be voided, or procedures to adjust the measured Δp values and final results shall be used, subject to the approval of the Administrator.

2.3 Temperature Gauge. A thermocouple, liquid-filled bulb thermometer, bimetallic thermometer, mercury-in-glass thermometer, or other gauge capable of measuring temperature to within 1.5 percent of the minimum absolute stack temperature shall be used. The temperature gauge shall be attached to the pitot tube such that the sensor tip does not touch any metal; the gauge shall be in an interference-free arrangement with respect to the pitot tube face openings (see Figure 2-1 and also Figure 2-7 in Section 4). Alternate positions may be used if the pitot tube-temperature gauge system is calibrated according to the procedure in Section 4. Provided that a difference of not more than 1 percent in the average velocity measurement is introduced, the tem-

perature gauge need not be attached to the pitot tube; this alternative is subject to the approval of the Administrator.

2.4 Pressure Probe and Gauge. A piezometer tube and mercury- or water-filled U-tube manometer capable of measuring stack pressure to within 2.5 mm (0.1 in.) Hg is used. The static tap of a standard type pitot tube or one leg of a Type X pitot tube with the face opening planes positioned parallel to the gas flow may also be used as the pressure probe.

2.5 Barometer. A mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg) may be used. In many cases, the barometric reading may be obtained from a nearby national weather service station, in which case the station value (which is the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and the sampling point shall be applied at a rate of minus 2.5 mm (0.1 in.) Hg per 30-meter (100 foot) elevation increase, or vice-versa for elevation decrease.

2.6 Gas Density Determination Equipment. Method 3 equipment, if needed (see Section 3.6), to determine the stack gas dry molecular weight, and Reference Method 4 or Method 5 equipment for moisture content determination; other methods may be used subject to approval of the Administrator.

2.7 Calibration Pitot Tube. When calibration of the Type S pitot tube is necessary (see Section 4), a standard pitot tube is used as a reference. The standard pitot tube shall, preferably, have a known coefficient, obtained either (1) directly from the National Bureau of Standards, Route 270, Quince Orchard Road, Gaithersburg,

Maryland, or (2) by calibration against another standard pitot tube with an NBS-traceable coefficient. Alternatively, a standard pitot tube designed according to the criteria given in 2.7.1 through 2.7.5 below and illustrated in Figure 2-4 (see also Citations 7, 8, and 17 in Section 6) may be used. Pitot tubes designed according to these specifications will have baseline coefficients of about 0.99±0.01.

2.7.1 Hemispherical (shown in Figure 2-4), ellipsoidal, or conical tip.

2.7.2 A minimum of six diameters straight run (based upon $D$, the external diameter of the tube) between the tip and the static pressure holes.

2.7.3 A minimum of eight diameters straight run between the static pressure holes and the centerline of the external tube, following the 90 degree bend.

2.7.4 Static pressure holes of equal size (approximately 0.1 $D$), equally spaced in a piezometer ring configuration.

2.7.5 Ninety degree bend, with curved or mitered junction.

2.8 Differential Pressure Gauge for Type S Pitot Tube Calibration. An inclined manometer or equivalent is used. If the single-velocity calibration technique is employed (see Section 4.1.2.3), the calibration differential pressure gauge shall be readable to the nearest 0.13 mm $H_2O$ (0.005 in. $H_2O$). For multivelocity calibrations, the gauge shall be readable to the nearest 1.3 mm $H_2O$ (0.005 in $H_2O$) for Δp values between 1.3 and 25 mm $H_2O$ (0.05 and 1.0 in. $H_2O$), and to the nearest 1.3 mm $H_2O$ (0.05 in. $H_2O$) for Δp values above 25 mm $H_2O$ (1.0 in. $H_2O$). A special, more sensitive gauge will be required to read Δp values below 1.3 mm $H_2O$ [0.05 in. $H_2O$] (see Citation 18 in Section 6).



CURVED OR MITERED JUNCTION

STATIC HOLES (~0.1D)
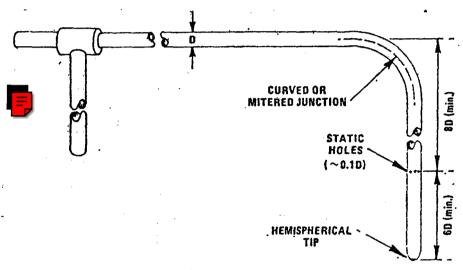
HEMISPHERICAL TIP

8D (min.)

6D (min.)

*Figure 2-4. Standard pitot tube design specifications.*

**3. Procedure**

3.1 Set up the apparatus as shown in Figure 2-1. Capillary tubing or surge tanks installed between the manometer and pitot tube may be used to dampen Δp fluctuations. It is recommended, but not required, that a pretest leak-check be conducted, as follows: (1) blow through the pitot impact opening until at least 7.6 cm (3 in.) $H_2O$ velocity pressure registers on the manometer; then, close off the impact opening. The pressure shall remain stable for at least 15 seconds; (2) do the same for the static pressure side, except using suction to obtain the minimum of 7.6 cm (3 in.) $H_2O$. Other leak-check procedures, subject to the approval of the Administrator, may be used.

3.2 Level and zero the manometer. Because the ma-

nometer level and zero may drift due to vibrations and temperature changes, make periodic checks during the traverse. Record all necessary data as shown in the example data sheet (Figure 2-5).

3.3 Measure the velocity head and temperature at the traverse points specified by Method 1. Ensure that the proper differential pressure gauge is being used for the range of Δp values encountered (see Section 2.2). If it is necessary to change to a more sensitive gauge, do so, and remeasure the Δp and temperature readings at each traverse point. Conduct a post-test leak-check (mandatory), as described in Section 3.1 above, to validate the traverse run.

3.4 Measure the static pressure in the stack. One reading is usually adequate.

3.5 Determine the atmospheric pressure.

RULES AND REGULATIONS

PLANT _____

DATE _____ RUN NO. _____

STACK DIAMETER OR DIMENSIONS, m(in.) _____

BAROMETRIC PRESSURE, mm Hg (in. Hg)_____

CROSS SECTIONAL AREA, m²(ft²) _____

OPERATORS _____

PITOT TUBE I.D. NO. _____

AVG. COEFFICIENT, Cp = _____

LAST DATE CALIBRATED_____

**SCHEMATIC OF STACK CROSS SECTION**

| Traverse Pt. No. | Vel. Hd., $\Delta p$ mm (in.) H$_2$O | Stack Temperature | | $P_g$ mm Hg (in.Hg) | $\sqrt{\Delta p}$ |
|---|---|---|---|---|---|
| | | $t_s$, °C (°F) | $T_s$, °K (°R) | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | Average | | | |

Figure 2-5. Velocity traverse data.

41764 · RULES AND REGULATIONS

3.6 Determine the stack gas dry molecular weight. For combustion processes or processes that emit essentially $CO_2$, $O_2$, CO, and $N_2$, use Method 3. For processes emitting essentially air, an analysis need not be conducted; use a dry molecular weight of 29.0. For other processes, other methods, subject to the approval of the Administrator, must be used.

3.7 Obtain the moisture content from Reference Method 4 (or equivalent) or from Method 5.

3.8 Determine the cross-sectional area of the stack or duct at the sampling location. Whenever possible, physically measure the stack dimensions rather than using blueprints.

**4. Calibration**

4.1 Type S Pitot Tube. Before its initial use, carefully examine the Type S pitot tube in top, side, and end views to verify that the face openings of the tube are aligned within the specifications illustrated in Figure 2-2 or 2-3. The pitot tube shall not be used if it fails to meet these alignment specifications.

After verifying the face opening alignment, measure and record the following dimensions of the pitot tube:

(a) the external tubing diameter (dimension $D_t$, Figure 2-2b); and (b) the base-to-opening plane distances (dimensions $P_A$ and $P_B$, Figure 2-2b). If $D_t$ is between 0.48 and 0.95 cm (¾₆ and ⅜ in.) and if $P_A$ and $P_B$ are equal and between 1.05 and 1.50 $R_t$, there are two possible options: (1) the pitot tube may be calibrated according to the procedure outlined in Sections 4.1.2 through 4.1.5 below, or (2) a baseline (isolated tube) coefficient value of 0.84 may be assigned to the pitot tube. Note, however, that if the pitot tube is part of an assembly, calibration may still be required, despite knowledge of the baseline coefficient value (see Section 4.1.1).

If $D_t$, $P_A$, and $P_B$ are outside the specified limits, the pitot tube must be calibrated as outlined in 4.1.2 through 4.1.5 below.
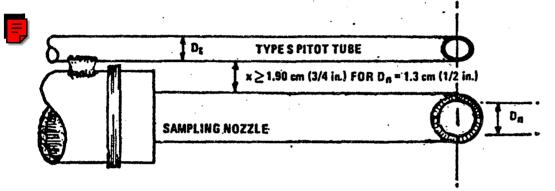
4.1.1 Type S Pitot Tube Assemblies. During sample and velocity traverses, the isolated Type S pitot tube is not always used; in many instances, the pitot tube is used in combination with other source-sampling components (thermocouple, sampling probe, nozzle) as part of an "assembly." The presence of other sampling components can sometimes affect the baseline value of the Type S pitot tube coefficient (Citation 9 in Section 6); therefore an assigned (or otherwise known) baseline coefficient

value may or may not be valid for a given assembly. The baseline and assembly coefficient values will be identical only when the relative placement of the components in the assembly is such that aerodynamic interference effects are eliminated. Figures 2-6 through 2-8 illustrate interference-free component arrangements for Type S pitot tubes having external tubing diameters between 0.48 and 0.95 cm (¾₆ and ⅜ in.). Type S pitot tube assemblies that fail to meet any or all of the specifications of Figures 2-6 through 2-8 shall be calibrated according to the procedure outlined in Sections 4.1.2 through 4.1.5 below, and prior to calibration, the values of the intercomponent spacings (pitot-nozzle, pitot-thermocouple, pitot-probe sheath) shall be measured and recorded.

NOTE.—Do not use any Type S pitot tube assembly which is constructed such that the impact pressure opening plane of the pitot tube is below the entry plane of the nozzle (see Figure 2-6b).

4.1.2 Calibration Setup. If the Type S pitot tube is to be calibrated, one leg of the tube shall be permanently marked A, and the other, B. Calibration shall be done in a flow system having the following essential design features:



$D_t$ TYPE S PITOT TUBE

$x \geq 1.90$ cm (3/4 in.) FOR $D_n = 1.3$ cm (1/2 in.)

SAMPLING NOZZLE

$D_n$

**A. BOTTOM VIEW; SHOWING MINIMUM PITOT-NOZZLE SEPARATION.**

SAMPLING PROBE

SAMPLING NOZZLE

STATIC PRESSURE OPENING PLANE

$D_t$

IMPACT PRESSURE OPENING PLANE

TYPE S PITOT TUBE

NOZZLE ENTRY PLANE

**B. SIDE VIEW; TO PREVENT PITOT TUBE FROM INTERFERING WITH GAS FLOW STREAMLINES APPROACHING THE NOZZLE, THE IMPACT PRESSURE OPENING PLANE OF THE PITOT TUBE SHALL BE EVEN WITH OR ABOVE THE NOZZLE ENTRY PLANE.**
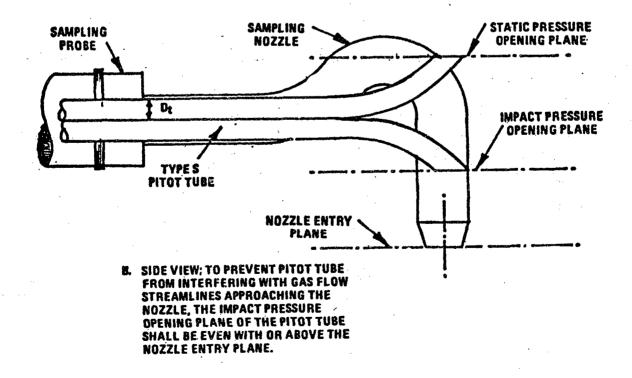
Figure 2-6. Proper pitot tube - sampling nozzle configuration to prevent aerodynamic interference; buttonhook - type nozzle; centers of nozzle and pitot opening aligned; $D_t$ between 0.48 and 0.95 cm (3/16 and 3/8 in.).

W ≥ 7.62 cm
(3 in.)

THERMOCOUPLE

Z ≥ 1.90 cm (3/4 in.)

$D_t$  TYPE S PITOT TUBE

SAMPLE PROBE

OR

Z ≥ 5.04 cm
(2 in.)

THERMOCOUPLE

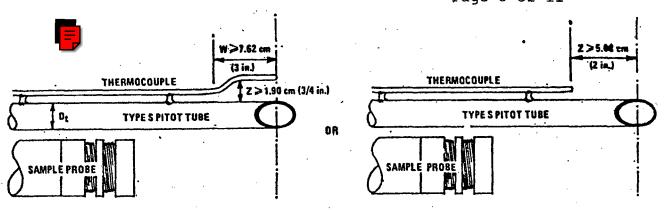TYPE S PITOT TUBE

SAMPLE PROBE

Figure 2-7. Proper thermocouple placement to prevent interference;
$D_t$ between 0.48 and 0.95 cm (3/16 and 3/8 in.).

$D_t$  TYPE S PITOT TUBE

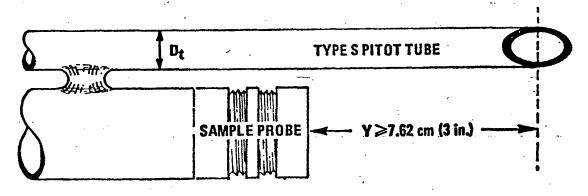SAMPLE PROBE ← Y ≥ 7.62 cm (3 in.) →

## Figure 2-8. Minimum pitot-sample probe separation needed to prevent interference; $D_t$ between 0.48 and 0.95 cm (3/16 and 3/8 in.).

4.1.2.1 The flowing gas stream must be confined to a duct of definite cross-sectional area, either circular or rectangular. For circular cross-sections, the minimum duct diameter shall be 30.5 cm (12 in.); for rectangular cross-sections, the width (shorter side) shall be at least 25.4 cm (10 in.).

4.1.2.2 The cross-sectional area of the calibration duct must be constant over a distance of 10 or more duct diameters. For a rectangular cross-section, use an equivalent diameter, calculated from the following equation, to determine the number of duct diameters:

$$D_e = \frac{2LW}{(L+W)}$$

Equation 2-1

where:
$D_e$ = Equivalent diameter
$L$ = Length
$W$ = Width

To ensure the presence of stable, fully developed flow patterns at the calibration site, or "test section," the site must be located at least eight diameters downstream and two diameters upstream from the nearest disturbances.

NOTE.—The eight- and two-diameter criteria are not absolute; other test section locations may be used (subject to approval of the Administrator), provided that the flow at the test site is stable and demonstrably parallel to the duct axis.

4.1.2.3 The flow system shall have the capacity to generate a test-section velocity around 915 m/min (3,000

ft/min). This velocity must be constant with time to guarantee steady flow during calibration. Note that Type S pitot tube coefficients obtained by single-velocity calibration at 915 m/min (3,000 ft/min) will generally be valid to within ±3 percent for the measurement of velocities above 305 m/min (1,000 ft/min) and to within ±5 to 6 percent for the measurement of velocities between 180 and 305 m/min (600 and 1,000 ft/min). If a more precise correlation between $C$, and velocity is desired, the flow system shall have the capacity to generate at least four distinct, time-invariant test-section velocities covering the velocity range from 180 to 1,525 m/min (600 to 5,000 ft/min), and calibration data shall be taken at regular velocity intervals over this range (see Citations 9 and 14 in Section 6 for details).

4.1.2.4 Two entry ports, one each for the standard and Type S pitot tubes, shall be cut in the test section; the standard pitot entry port shall be located slightly downstream of the Type S port, so that the standard and Type S impact openings will lie in the same cross-sectional plane during calibration. To facilitate alignment of the pitot tubes during calibration, it is advisable that the test section be constructed of plexiglas or some other transparent material.

4.1.3 Calibration Procedure. Note that this procedure is a general one and must not be used without first referring to the special considerations presented in Section 4.1.5. Note also that this procedure applies only to single-velocity calibration. To obtain calibration data for the A and B sides of the Type S pitot tube, proceed as follows:

4.1.3.1 Make sure that the manometer is properly filled and that the oil is free from contamination and is of the proper density. Inspect and leak-check all pitot lines; repair or replace if necessary.

4.1.3.2 Level and zero the manometer. Turn on the fan and allow the flow to stabilize. Seal the Type S entry port.

4.1.3.3 Ensure that the manometer is level and zeroed. Position the standard pitot tube at the calibration point (determined as outlined in Section 4.1.5.1), and align the tube so that its tip is pointed directly into the flow. Particular care should be taken in aligning the tube to avoid yaw and pitch angles. Make sure that the entry port surrounding the tube is properly sealed.

4.1.3.4 Read $\Delta p_{std}$ and record its value in a data table similar to the one shown in Figure 2-9. Remove the standard pitot tube from the duct and disconnect it from the manometer. Seal the standard entry port.

4.1.3.5 Connect the Type S pitot tube to the manometer. Open the Type S entry port. Check the manometer level and zero. Insert and align the Type S pitot tube so that its A side impact opening is at the same point as was the standard pitot tube and is pointed directly into the flow. Make sure that the entry port surrounding the tube is properly sealed.

4.1.3.6 Read $\Delta p_s$ and enter its value in the data table. Remove the Type S pitot tube from the duct and disconnect it from the manometer.

4.1.3.7 Repeat steps 4.1.3.3 through 4.1.3.6 above until three pairs of $\Delta p$ readings have been obtained.

4.1.3.8 Repeat steps 4.1.3.3 through 4.1.3.7 above for the B side of the Type S pitot tube.

4.1.3.9 Perform calculations, as described in Section 4.1.4 below.

4.1.4 Calculations.

4.1.4.1 For each of the six pairs of $\Delta p$ readings (i.e., three from side A and three from side B) obtained in Section 4.1.3 above, calculate the value of the Type S pitot tube coefficient as follows:

**41766**　　　　　　　　　**RULES AND REGULATIONS**

PITOT TUBE IDENTIFICATION NUMBER: _____ DATE: _____

CALIBRATED BY: _____

| "A" SIDE CALIBRATION | | | |
|---|---|---|---|
| RUN NO. | $\Delta p_{std}$ cm H₂O (in. H₂O) | $\Delta p(s)$ cm H₂O (in. H₂O) | $C_p(s)$ | DEVIATION $C_p(s) \cdot \bar{C}_p(A)$ |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| | | $\bar{C}_p$ (SIDE A) | | |

| "B" SIDE CALIBRATION | | | |
|---|---|---|---|
| RUN NO. | $\Delta p_{std}$ cm H₂O (in. H₂O) | $\Delta p(s)$ cm H₂O (in. H₂O) | $C_p(s)$ | DEVIATION $C_p(s) \cdot \bar{C}_p(B)$ |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| | | $\bar{C}_p$ (SIDE B) | | |

$$\text{AVERAGE DEVIATION} = \sigma(A \text{ OR } B) = \frac{\sum\limits_{1}^{3} \left| C_p(s) - \bar{C}_p(A \text{ OR } B) \right|}{3} \quad \longleftarrow \text{MUST BE} \leqslant 0.01$$

$$\left| \bar{C}_p \text{ (SIDE A)} - \bar{C}_p \text{ (SIDE B)} \right| \longleftarrow \text{MUST BE} \leqslant 0.01$$

**Figure 2-9. Pitot tube calibration data.**

$$C_{p(s)} = C_{p(std)} \sqrt{\frac{\Delta p_{std}}{\Delta p_s}}$$

**Equation 2-2**

where:
$C_{p(s)}$ =Type S pitot tube coefficient
$C_{p(std)}$ =Standard pitot tube coefficient; use 0.99 if the coefficient is unknown and the tube is designed

according to the criteria of Sections 2.7.1 to 2.7.5 of this method.
$\Delta p_{std}$=Velocity head measured by the standard pitot tube, cm H₂O (in. H₂O)
$\Delta p_s$=Velocity head measured by the Type S pitot tube, cm H₂O (in. H₂O)

4.1.4.2 Calculate $\bar{C}_p$ (side A), the mean A-side coefficient, and $\bar{C}_p$ (side B), the mean B-side coefficient; calculate the difference between these two average values.

4.1.4.3 Calculate the deviation of each of the three A-side values of $C_{p(s)}$ from $\bar{C}_p$ (side A), and the deviation of each B-side value of $C_{p(s)}$ from $\bar{C}_p$ (side B). Use the following equation:

$$\text{Deviation} = C_{p(s)} - \bar{C}_p(A \text{ or } B)$$

**Equation 2-3**

4.1.4.4 Calculate $\sigma$, the average deviation from the mean, for both the A and B sides of the pitot tube. Use the following equation:

$$\sigma \text{ (side A or B)} = \frac{\sum\limits_{1}^{3} |C_{p(s)} - \bar{C}_p(A \text{ or } B)|}{3}$$

**Equation 2-4**

4.1.4.5 Use the Type S pitot tube only if the values of $\sigma$ (side A) and $\sigma$ (side B) are less than or equal to 0.01 and if the absolute value of the difference between $\bar{C}_p$ (A) and $\bar{C}_p$ (B) is 0.01 or less.

4.1.5 Special considerations.

4.1.5.1 Selection of calibration point.

4.1.5.1.1 When an isolated Type S pitot tube is calibrated, select a calibration point at or near the center of the duct, and follow the procedures outlined in Sections 4.1.3 and 4.1.4 above. The Type S pitot coefficients so obtained, i.e., $\bar{C}_p$ (side A) and $\bar{C}_p$ (side B), will be valid, so long as either: (1) the isolated pitot tube is used; or (2) the pitot tube is used with other components (nozzle, thermocouple, sample probe) in an arrangement that is free from aerodynamic interference effects (see Figures 2-6 through 2-8).

4.1.5.1.2 For Type S pitot tube-thermocouple combinations (without sample probe), select a calibration point at or near the center of the duct, and follow the procedures outlined in Sections 4.1.3 and 4.1.4 above. The coefficients so obtained will be valid so long as the pitot tube-thermocouple combination is used by itself or with other components in an interference-free arrangement (Figures 2-6 and 2-8).

4.1.5.1.3 For assemblies with sample probes, the calibration point should be located at or near the center of the duct; however, insertion of a probe sheath into a small duct may cause significant cross-sectional area blockage and yield incorrect coefficient values (Citation 9 in Section 6). Therefore, to minimize the blockage effect, the calibration point may be a few inches off-center if necessary. The actual blockage effect will be negligible when the theoretical blockage, as determined by a projected-area model of the probe sheath, is 2 percent or less of the duct cross-sectional area for assemblies without external sheaths (Figure 2-10a), and 3 percent or less for assemblies with external sheaths (Figure 2-10b).

4.1.5.2 For those probe assemblies in which pitot tube-nozzle interference is a factor (i.e., those in which the pitot-nozzel separation distance fails to meet the specification illustrated in Figure 2-6a), the value of $C_{p(s)}$ depends upon the amount of free-space between the tube and nozzle, and therefore is a function of nozzle size. In these instances, separate calibrations shall be performed with each of the commonly used nozzle sizes in place. Note that the single-velocity calibration technique is acceptable for this purpose, even though the larger nozzle sizes (>0.635 cm or ¼ in.) are not ordinarily used for isokinetic sampling at velocities around 915 m/min (3,000 ft/min), which is the calibration velocity; note also that it is not necessary to draw an isokinetic sample during calibration (see Citation 10 in Section 6).

4.1.5.3 For a probe assembly constructed such that its pitot tube is always used in the same orientation, only one side of the pitot tube need be calibrated (the side which will face the flow). The pitot tube must still meet the alignment specifications of Figure 2-2 or 2-3, however, and must have an average deviation ($\sigma$) value of 0.01 or less (see Section 4.1.4.4).

**RULES AND REGULATIONS**



ESTIMATED SHEATH BLOCKAGE (%) $= \left[\dfrac{I \times W}{DUCT\ AREA}\right] \times 100$
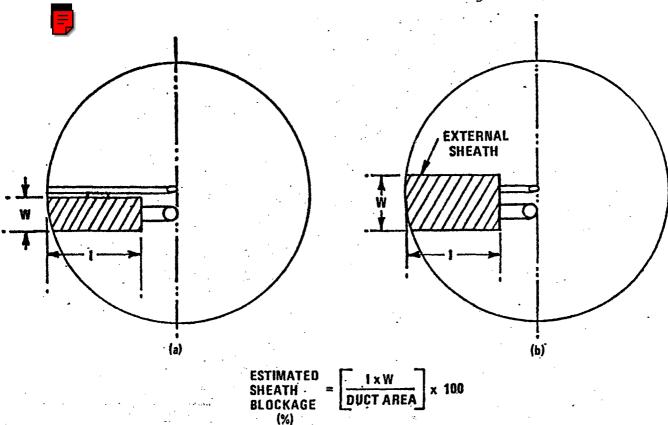
**Figure 2-10. Projected-area models for typical pitot tube assemblies.**

**4.1.6 Field Use and Recalibration.**

**4.1.6.1 Field Use.**

**4.1.6.1.1** When a Type S pitot tube (isolated tube or assembly) is used in the field, the appropriate coefficient value (whether assigned or obtained by calibration) shall be used to perform velocity calculations. For calibrated Type S pitot tubes, the A side coefficient shall be used when the A side of the tube faces the flow, and the B side coefficient shall be used when the B side faces the flow; alternatively, the arithmetic average of the A and B side coefficient values may be used, irrespective of which side faces the flow.

**4.1.6.1.2** When a probe assembly is used to sample a small duct (12 to 36 in. in diameter), the probe sheath sometimes blocks a significant part of the duct cross-section, causing a reduction in the effective value of $\overline{C}_{p\,(s)}$. Consult Citation 9 in Section 6 for details. Conventional pitot-sampling probe assemblies are not recommended for use in ducts having inside diameters smaller than 12 inches (Citation 16 in Section 6).

**4.1.6.2 Recalibration.**

**4.1.6.2.1** Isolated Pitot Tubes. After each field use, the pitot tube shall be carefully reexamined in top, side, and end views. If the pitot face openings are still aligned within the specifications illustrated in Figure 2-2 or 2-3, it can be assumed that the baseline coefficient of the pitot tube has not changed. If, however, the tube has been damaged to the extent that it no longer meets the specifications of Figure 2-2 or 2-3, the damage shall either be repaired to restore proper alignment of the face openings or the tube shall be discarded.

**4.1.6.2.2** Pitot Tube Assemblies. After each field use, check the face opening alignment of the pitot tube, as in Section 4.1.6.2.1; also, remeasure the intercomponent spacings of the assembly. If the intercomponent spacings have not changed and the face opening alignment is acceptable, it can be assumed that the coefficient of the assembly has not changed. If the face opening alignment is no longer within the specifications of Figures 2-2 or 2-3, either repair the damage or replace the pitot tube (calibrating the new assembly, if necessary). If the intercomponent spacings have changed, restore the original spacings or recalibrate the assembly.

**4.2** Standard pitot tube (if applicable). If a standard pitot tube is used for the velocity traverse, the tube shall be constructed according to the criteria of Section 2.7 and shall be assigned a baseline coefficient value of 0.99. If the standard pitot tube is used as part of an assembly,

the tube shall be in an interference-free arrangement (subject to the approval of the Administrator).

**4.3** Temperature Gauges. After each field use, calibrate dial thermometers, liquid-filled bulb thermometers, thermocouple-potentiometer systems, and other gauges at a temperature within 10 percent of the average absolute stack temperature. For temperatures up to 405° C (761° F), use an ASTM mercury-in-glass reference thermometer, or equivalent, as a reference; alternatively, either a reference thermocouple and potentiometer (calibrated by NBS) or thermometric fixed points, e.g., ice bath and boiling water (corrected for barometric pressure) may be used. For temperatures above 405° C (761° F), use an NBS-calibrated reference thermocouple-potentiometer system or an alternate reference, subject to the approval of the Administrator.

If, during calibration, the absolute temperatures measured with the gauge being calibrated and the reference gauge agree within 1.5 percent, the temperature data taken in the field shall be considered valid. Otherwise, the pollutant emission test shall either be considered invalid or adjustments (if appropriate) of the test results shall be made, subject to the approval of the Administrator.

**4.4** Barometer. Calibrate the barometer used against a mercury barometer.

**5. Calculations**

Carry out calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after final calculation.

**5.1** Nomenclature.

$A =$ Cross-sectional area of stack, m² (ft²).

$B_{ws} =$ Water vapor in the gas stream (from Method 5 or Reference Method 4), proportion by volume.

$C_p =$ Pitot tube coefficient, dimensionless.

$K_p =$ Pitot tube constant,

$34.97\ \dfrac{m}{sec}\left[\dfrac{(g/g\text{-mole})(mm\ Hg)}{(°K)(mm\ H_2O)}\right]^{1/2}$

for the metric system and

$85.49\ \dfrac{ft}{sec}\left[\dfrac{(lb/lb\text{-mole})(in.\ Hg)}{(°R)(in.\ H_2O)}\right]^{1/2}$

for the English system.

$M_d =$ Molecular weight of stack gas, dry basis (see Section 3.6) g/g-mole (lb/lb-mole).

$M_s =$ Molecular weight of stack gas, wet basis, g/g-mole (lb/lb-mole).

$= M_d\,(1 - B_{ws}) + 18.0\ B_{ws}$  Equation 2-5

$P_{bar} =$ Barometric pressure at measurement site, mm Hg (in. Hg).

$P_g =$ Stack static pressure, mm Hg (in. Hg).

$P_s =$ Absolute stack gas pressure, mm Hg (in. Hg).

$= P_{bar} + P_g$  Equation 2-6

$P_{std} =$ Standard absolute pressure, 760 mm Hg (29.92 in. Hg).

$Q_{sd} =$ Dry volumetric stack gas flow rate corrected to standard conditions, dscm/hr (dscf/hr).

$t_s =$ Stack temperature, °C (°F).

$T_s =$ Absolute stack temperature, °K (°R).

$= 273 + t_s$ for metric  Equation 2-7

$= 460 + t_s$ for English  Equation 2-8

$T_{std} =$ Standard absolute temperature, 293 °K (528° R).

$v_s =$ Average stack gas velocity, m/sec (ft/sec).

$\Delta p =$ Velocity head of stack gas, mm H₂O (in. H₂O).

$3,600 =$ Conversion factor, sec/hr.

$18.0 =$ Molecular weight of water, g/g-mole (lb-lb-mole).

**5.2** Average stack gas velocity.

$$v_s = K_p C_p (\sqrt{\Delta p})_{avg}\sqrt{\dfrac{T_{s(avg)}}{P_s M_s}}$$

Equation 2-9

**5.3** Average stack gas dry volumetric flow rate.

$$Q_{sd} = 3,600(1 - B_{ws})v_s A\left(\dfrac{T_{std}}{T_{s(avg)}}\right)\left(\dfrac{P_s}{P_{std}}\right)$$

Equation 2-10

**6. Bibliography**

1. Mark, L. S. Mechanical Engineers' Handbook. New York, McGraw-Hill Book Co., Inc. 1951.

2. Perry, J. H. Chemical Engineers' Handbook. New York, McGraw-Hill Book Co., Inc. 1960.

42768

**RULES AND REGULATIONS**

3. Shigehara, R. T., W. F. Todd, and W. S. Smith. Significance of Errors in Stack Sampling Measurements. U.S. Environmental Protection Agency, Research Triangle Park, N.C. (Presented at the Annual Meeting of the Air Pollution Control Association, St. Louis, Mo., June 14-19, 1970.)

4. Standard Method for Sampling Stacks for Particulate Matter. In: 1971 Book of ASTM Standards, Part 23. Philadelphia, Pa. 1971. ASTM Designation D 2928-71.

5. Vennard, J. K. Elementary Fluid Mechanics. New York. John Wiley and Sons, Inc. 1947.

6. Fluid Meters—Their Theory and Application. American Society of Mechanical Engineers, New York, N.Y. 1959.

7. ASHRAE Handbook of Fundamentals. 1972. p. 208.

8. Annual Book of ASTM Standards, Part 26. 1974. p. 648.

9. Vollaro, R. F. Guidelines for Type S Pitot Tube Calibration. U.S. Environmental Protection Agency, Research Triangle Park, N.C. (Presented at 1st Annual Meeting, Source Evaluation Society, Dayton, Ohio, September 18, 1975.)

10. Vollaro, R. F. A Type S Pitot Tube Calibration Study. U.S. Environmental Protection Agency, Emission Measurement Branch, Research Triangle Park, N.C. July 1974.

11. Vollaro, R. F. The Effects of Impact Opening Misalignment on the Value of the Type S Pitot Tube Coefficient. U.S. Environmental Protection Agency, Emission Measurement Branch, Research Triangle Park, N.C. October 1976.

12. Vollaro, R. F. Establishment of a Baseline Coefficient Value for Properly Constructed Type S Pitot Tubes. U.S. Environmental Protection Agency, Emission Measurement Branch, Research Triangle Park, N.C. November 1976.

13. Vollaro, R. F. An Evaluation of Single Velocity Calibration Techniques as a Means of Determining Type S Pitot Tube Coefficients. U.S. Environmental Protection Agency, Emission Measurement Branch, Research Triangle Park, N.C. August 1975.

14. Vollaro, R. F. The Use of Type S Pitot Tubes for the Measurement of Low Velocities. U.S. Environmental Protection Agency, Emission Measurement Branch, Research Triangle Park, N.C. November 1976.

15. Smith, Marvin L. Velocity Calibration of EPA Type Source Sampling Probe. United Technologies Corporation, Pratt and Whitney Aircraft Division, East Hartford, Conn. 1975.

16. Vollaro, R. F. Recommended Procedure for Sample Traverses in Ducts Smaller than 12 Inches in Diameter. U.S. Environmental Protection Agency, Emission Measurement Branch, Research Triangle Park, N.C. November 1976.

17. Ower, E. and R. C. Pankhurst. The Measurement of Air Flow, 4th Ed., London, Pergamon Press. 1966.

18. Vollaro, R. F. A survey of Commercially Available Instrumentation for the Measurement of Low-Range Gas Velocities. U.S. Environmental Protection Agency, Emission Measurement Branch, Research Triangle Park, N.C. November 1976. (Unpublished Paper)

19. Gnyp, A. W., C. C. St. Pierre, D. S. Smith, D. Mozzon, and J. Steiner. An Experimental Investigation of the Effect of Pitot Tube-Sampling Probe Configurations on the Magnitude of the S Type Pitot Tube Coefficient for Commercially Available Source Sampling

## 11.0 REFERENCES

1. Smith, F., D. E. Wagoner, and A. C. Nelson, Jr. Guidelines for Development of a Quality Assurance Program: Volume I - Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube). EPA-650/4-74-005-a. February 1974.

2. Hamil, H. F. Laboratory and Field Evaluations of EPA Methods 2, 6, and 7. Southwest Research Institute. EPA Contract 68-02-0626. October 1973.

3. Hamil, H. F. and R. E. Thomas. Collaborative Study of Method for the Determination of Particulate Matter Emissions from Stationary Sources (Municipal Incinerators). Southwest Research Institute. EPA-650/4-74-022. July 1974.

4. Hamil, H. F. and R. E. Thomas. Collaborative Study of Method for Determination of Stack Gas Velocity and Volumetric Flow Rate in Conjunction with EPA Method 5. Southwest Research Institute. EPA-650/4-74-033. September 1974.

5. Hamil, H. F. and R. E. Thomas. Collaborative Study of Particulate Emission Measurements by EPA Methods 2, 3, and 5 using Paired Particulate Sampling Trains (Municipal Incinerators). Southwest Research Institute EPA-600/4-76-014.

6. Vollaro, R. F. A Survey of Commercially Available Instrumentation for the Measurement of Low-Range Gas Velocities. U.S. Environmental Protection Agency, Emission Measurement Branch, Research Triangle Park, N.C. November 1976. (Unpublished Paper)

7. Vollaro, R. F. Guidelines for Type S Pitot Tube Calibration. U.S. Environmental Protection Agency, Research Triangle Park, N.C. (Presented at 1st Annual Meeting, Source Evaluation Society, Dayton, Ohio, September 18, 1975.)

8. Vollaro, R. F. The Use of Type S Pitot Tubes for the Measurement of Low Velocities. U.S. Environmental Protection Agency, Emission Measurement Branch, Research Triangle Park, N.C. November 1976.

9.  Smith, F. and D. E. Wagoner. Guidelines for Development of a Quality Assurance Program: Volume IV - Determination of Particulate Emissions from Stationary Sources. EPA-650/4-74-005-d. August 1974.

10. Quality Assurance Handbook for Air Pollution Measurement Systems - Volume I, Principles. EPA-600/9-76-005. March 1976.

11. Alexander, K. Thermocouple Calibration Procedure Evaluation. U.S. Environmental Protection Agency, Emissions Standards and Engineering Division, Research Triangle Park, N.C. Source Evaluation Society Newsletter, June 1978.
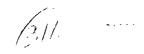
12.0  DATA FORMS

Blank data forms are provided on the following pages for the convenience of the Handbook user.  Many of these forms are taken or adapted from EPA forms, Reference 1, and other references.  No documentation is given on these forms as it would detract from their usefulness.  The titles are also placed at the top of the figure as is customary for a data form.  In order to relate the form to the text, a form number is given in the lower right-hand corner, e.g., Form M2 - 2.5, indicates that the form is Figure 2.5, the fifth figure in Section 3.1.2, of the written description for Method 2 (M2).  Future revisions of these forms, if any, can be documented by 2.5A, 2.5B, etc.  Seven of the data forms listed below are included in this section.  Four are in the Method Highlights subsection as shown by the (MH) following the form number.

| Form | Title |
|---|---|
| 1.2 | Example of a Procurement Log |
| 1.7 | Type S Pitot Tube Inspection Data Form |
| 2.5 | Pitot Tube Calibration Data |
| 2.10 | Stack Temperature Sensor Calibration Data Form |
| 2.12 | Differential Pressure Gauge Calibration Data Form |
| 3.1 (MH) | Pretest Sampling Checks |
| 3.2 (MH) | Pretest Preparations |
| 4.1 | Method 2 Gas Velocity and Volume Data Form |
| 4.2 (MH) | On-Site Measurements Checklist |
| 5.1 (MH) | Posttest Sampling Checks |
| 8.1 | Stack Gas Velocity and Volumetric Flow Rate Determination Checklist to be Used by Auditor |

PROCUREMENT LOG

| Item description | Quantity | Purchase order number | Vendor | Date | | Cost | Dispo-sition | Comments |
|---|---|---|---|---|---|---|---|---|
| | | | | Ordered | Received | | | |
| | | | | | | | | |

# TYPE S PITOT TUBE INSPECTION DATA FORM

Pitot tube assembly level? _____ yes _____ no

Pitot tube openings damaged? _____ yes (explain below) _____ no

$\alpha_1$ = _____° (<10°),  $\alpha_2$ = _____° (<10°),  $\beta_1$ = _____° (<5°),

  $\beta_2$ = _____° (<5°)

$\gamma$ = _____°,  $\theta$ = _____°,  A = _____ cm (in.)

z = A sin $\gamma$ = _____ cm (in.); <0.32 cm (<1/8 in.),

  w = A sin $\theta$ = _____ cm (in.); <.08 cm (<1/32 in.)

$P_A$ _____ cm (in.)  $P_b$ _____ cm (in.)

$D_t$ = _____ cm (in.)

Comments: _____

_____

_____

Calibration required? _____ yes _____ no

PITOT TUBE CALIBRATION DATA

Calibration pitot tube: type _____ size (OD) _____ ID number ____

Type S pitot tube ID number _____ $C_{p(std)}$ = _____

Calibration: date _____ performed by _____

### A-Side Calibration

| $\Delta p_{std}$, cm (in.) $H_2O$ | $\Delta p_s$, cm (in.) $H_2O$ | $C_{p(S)}$ [a] | DEV. [b] |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| Average | | | |

### B-Side Calibration

| $\Delta p_{std}$, cm (in.) $H_2O$ | $\Delta p_s$, cm (in.) $H_2O$ | $C_{p(S)}$ [a] | DEV. [b] |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| Average | | | |

[a] $C_{p(S)} = C_{p(std)} \sqrt{\dfrac{\Delta p_{std}}{\Delta p_s}}$ = _____

[b] DEV = $C_{p(S)} - \bar{C}_p$, (must be $\leq 0.01$)

$\bar{C}_p(A) - \bar{C}_p(B)$ = _____ (must be $\leq 0.01$).

Quality Assurance Handbook M2-2.5

# STACK TEMPERATURE SENSOR CALIBRATION DATA FORM

Date _____    Thermocouple number _____

Ambient temperature _____°C  Barometric pressure _____ in. Hg

Calibrator _____    Reference:  mercury-in-glass _____

                                     other _____

| Reference point number[a] | Source[b] (specify) | Reference thermometer temperature, °C | Thermocouple potentiometer temperature, °C | Temperature difference,[c] % |
|---|---|---|---|---|
|  |  |  |  |  |

[a] Every 30°C (50°F) for each reference point.

[b] Type of calibration system used.

[c] $\left[ \dfrac{(\text{ref temp, °C} + 273) - (\text{test thermom temp, °C} + 273)}{\text{ref temp, °C} + 273} \right] 100 \leq 1.5\%.$

# DIFFERENTIAL PRESSURE GAUGE CALIBRATION DATA FORM

Gauge type _____ Serial or ID number _____

Scale _____

| Gauge-oil manometer Δp | Differential pressure gauge Δp | Pressure difference % |
|---|---|---|
|  |  |  |

Calibration: _____ initial _____ posttest

Date calibrated _____ by _____

Quality Assurance Handbook M2-2.12

# METHOD 2 GAS VELOCITY AND VOLUME DATA FORM

| Plant and city | Run date |
|---|---|
|  |  |

| Sampling location | Clock time |
|---|---|
|  |  |

| Run number | Operator | Amb. temp., °F | Bar. press., in. Hg | Static press., in. $H_2O$ |
|---|---|---|---|---|
|  |  |  |  |  |

| Molecular wt. | Stack inside dimension, in. | | Pitot tube ($C_p$) |
|---|---|---|---|
|  | Diam. of side 1 | side 2 |  |
|  |  |  |  |

**Field data**

| Traverse point number | Position, in. | Velocity head ($\Delta p_s$), in. $H_2O$ | Stack temp., °F | Cyclonic flow determination | |
|---|---|---|---|---|---|
|  |  |  |  | $\Delta p_s$ at 0° reference | Angle ($\alpha$) which yields a null $\Delta p$ |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  | Average angle ($\alpha$)[a] |  |

[a] Average of $\alpha$ must be <10 degrees to be acceptable.

Quality Assurance Handbook M2-4.1

## STACK GAS VELOCITY AND VOLUMETRIC FLOW RATE
## DETERMINATION CHECKLIST TO BE USED BY AUDITOR

| Yes | No | Operation |
|-----|-----|-----------|
| | | **Presampling preparation** |
| _____ | _____ | 1. Knowledge of process conditions |
| _____ | _____ | 2. Calibration of pertinent equipment prior to each field tests |
| | | **On-site measurements** |
| _____ | _____ | 3. Pitot tube meets geometry requirements |
| _____ | _____ | 4. Manometer should be carefully leveled and the liquid column set exactly on zero |
| _____ | _____ | 5. Check for cyclonic flow |
| _____ | _____ | 6. Leak check after sample run |
| _____ | _____ | 7. Sampling port adequately plugged |
| _____ | _____ | 8. Process at correct operating level |
| _____ | _____ | 9. Pitot tube properly aligned along its roll and pitch axes throughout the traverse |
| _____ | _____ | 10. Pitot tube frequently cleared when measuring in a dust-laden gas |
| _____ | _____ | 11. Manometer has the correct sensitivity |
| _____ | _____ | 12. Staying at each traverse point long enough for the system to stabilize |
| _____ | _____ | 13. Measuring the stack gas static pressure and temperature |
| | | **Postsampling** |
| _____ | _____ | 14. All information recorded on data form as obtained |
| _____ | _____ | 15. Any unusual conditions recorded |
| _____ | _____ | 16. Independent check of calculations |
| _____ | _____ | 17. Temperature sensor calibrated |
| COMMENTS | | |
| | | |